METHYL BROMIDE ALTERNATIVES FOR APPLICATORS, COMMODITY OWNERS, SHIPPERS, AND THEIR AGENTS

U.S. ENVIRONMENTAL PROTECTION AGENCY

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Table of Contents

Common Acronyms

1,3-D	1,3-dichloropropene
A5	Article 5 Party
APHIS	Animal and Plant Health Inspection Service (USDA)
AQIS	Australian Quarantine and Inspection Service
CUE	Critical Use Exemption
CUN	Critical Use Nomination
EC	European Community
EPPO	European Plant Protection Organisation
IPPC	International Plant Protection Convention
ISPM	International Standard Phytosanitary Measure
MB	Methyl Bromide
MBAIS	Methyl Bromide Alternatives Information System (Australian database)
MBTOC	Methyl Bromide Technical Options Committee
MITC	Methylsiocyanate
MOP	Meeting of the Parties
NPPO	National Plant Protection Organization
OEWG	Open Ended Working Group
Pic	Chloropicrin
PHYTO	Plant and plant product export conditions database within AQIS
PPQ	Plant, Protection and Quarantine (APHIS)
QPS	Quarantine and Pre-shipment
SF	Sulfuryl fluoride
TEAP	Technology and Economic Assessment Panel
USA, US	United States of America
USDA	United States Department of Agriculture
US EPA	United States Environmental Protection Agency

Section I. Introduction and Overview

Alternatives for many quarantine and preshipment (QPS) uses of methyl bromide are known. The Quarantine and Preshipment Task Force of the Technology and Economic Assessment Panel of the *Montreal Protocol on Substances that Deplete the Ozone Layer* submitted these alternatives in a comprehensive report to the Montreal Protocol parties in October, 2009.

The U.S. Environmental Protection Agency (EPA) created this consolidated report to encourage applicators – commodity owners, shippers, and their agents - to review and consider the use of potential alternatives to lessen methyl bromide usage.

Alternatives for Quarantine Applications
With regard to quarantine treatments associated with international trade, the International Plant Protection Convention (IPPC) has a policy that alternatives to methyl bromide should be used wherever technically and economically feasible. Within the IPPC, a Technical Panel on Phytosanitary Treatments has promulgated a standard for treatments to be assessed against and is assessing alternatives and approving where sufficient data are available.

There are technically effective alternatives approved and in use for at least some of the major categories of current quarantine uses on commodities. Heat treatments are available for sawn timber and wood packing material, fumigation with phosphine or sulfuryl fluoride is available for particular trades with whole logs, and there are a number of alternative options in use for various perishables in international trade.

Development of methyl bromide alternatives for quarantine applications on commodities continues to be a difficult process, exacerbated by the multitude of commodities being treated, the diverse situations where treatments are applied, a constantly changing trade and regulatory landscape, requirements for bilateral agreement on QPS measures, requirement for very high levels of proven effectiveness, often for several different target species, lack of patent coverage or other commercial protection for some potential alternatives, and the low price and plentiful supply of methyl bromide for QPS purposes. Regulations favoring methyl bromide treatment or prescribing methyl bromide alone are a major barrier to adoption of alternatives as often there is little incentive for the regulation to be changed. A key barrier to the development of alternatives for soil treatment for growing plants of certified high health status is the rigorous testing required to prove and certify that an alternative is effective.

Alternatives for Preshipment Treatments
For preshipment treatments, the objective is to produce goods that are "pest-free" to some standard level. While in practice the target species are typically cosmopolitan insect pests (beetles, moths and psocids) associated with quality losses in storage, treatments are also expected to eliminate the other living insect species that may contaminate commodities, even when they do not pose a direct threat to the quality of the commodity.

For preshipment treatment of grains, there are several alternative fumigants which are available or near market and that can match the effectiveness and speed of action of methyl bromide. Where logistically possible, several alternative strategies are available that can deliver "pest-free" grain at the point of export. In-transit fumigation with phosphine may also be an option.

In many of these cases, where the alternatives are not already approved, there are various regulatory and other barriers to be overcome before the alternatives can be applied.

Methyl Bromide Emission Minimization

Methyl bromide emissions from fumigations can be minimized through the adoption of best practices, both directly through best use of the fumigant and indirectly by minimizing the need to re-treat after treatment failures. Methyl bromide can also be conserved to some extent. For example, in a commercial installation in China treating logs, residual gas from one fumigation chamber is transferred to a new fumigation. The concentration is then topped up to specification using new methyl bromide, with a savings of methyl bromide of about 30% use.

There are several commercially available processes for recapture of residual methyl bromide. Present installations have individual capacities of less than 50kg of fumigant, but higher capacity units are currently being installed. All commercially available recapture units are based on absorption onto active carbon, but subsequent treatment of the loaded carbon differs. Efficiencies of recapture are strongly dependent on good fumigation practices that minimises leakage during the exposure to the fumigant. Some specifications for QPS fumigations include a minimum residual concentration or percent retention at the end of the exposure. Examples vary from 21-60% retention, setting a limit on easily available fumigant for recapture. Taking into account losses in practice during fumigations, including sorption losses and leakage, it is estimated that 30-70% of initial dosage is available for recapture with good practice, depending on the load treated and other conditions. Commercially available recapture systems also offer the ability to release recaptured methyl bromide for reuse, with a savings in practice of about 30% of methyl bromide use. Costs of recapture are highly situation-dependent, but may typically add 50-100% to the cost of fumigation.

Regulations that Affect QPS Use

Methyl bromide, as a highly toxic gas, is subject to numerous restrictions and regulations that affect its use as QPS fumigant treatment.

Some Parties have discontinued use of QPS methyl bromide or have announced an intent to do so in the near future. The Russian Federation discontinued use of QPS methyl bromide with legislation that also terminated use of non-QPS material. Both the EC and Brazil have signaled they will discontinue QPS methyl bromide use soon.

Industrial and environmental regulations relating to methyl bromide fumigations vary widely between countries. In some, its use is severely restricted and may require recapture in some regions. National phytosanitary regulations specify set dosages for particular applications. There are relatively few cases (by total volume used) where methyl bromide is the sole treatment specified, though local circumstances may make it the only feasible option. This is particularly so for post-entry quarantine.

Illustrative examples of regulations affecting methyl bromide as a QPS fumigant are given in the full 2009 report.

Section II. Categories of Alternative Treatment for QPS Uses

The Methyl Bromide Technical Options Committee (MBTOC) (2002) recognized 13 different categories of alternative treatments that are approved by regulatory agencies as QPS treatments in one or more countries against specific quarantine (regulated) pests for disinfestation of particular perishable and durable commodities. For example, the Methyl Bromide Alternatives Information System (MBAIS) database (Australian Quarantine and Information System - AQIS 2009a) provides a listing of references to methyl bromide alternatives for QPS and other uses, such as heat, cold, and irradiation.

Existing alternatives to MB for QPS treatment of perishable and durable commodities are based on (1) pre-harvest practices and inspection procedures; (2) non-chemical (physical) treatments; and (3) chemical treatments.

Many quarantine treatments are “post-entry.” This is where a treatment is required either if inspection finds a quarantine organism in the shipment at the port of entry or quarantine or other treatments have been insufficient to adequately manage the risk of importing quarantine pests in sufficient numbers to be a quarantine threat. Many countries prohibit imports of particular cargos where the risk of carrying quarantine pests is unacceptable and there is no system or treatment available to manage this risk to an adequate level. In effect, this avoids the need for post-entry quarantine measures, including methyl bromide fumigation.

Typically, treatment options are more restricted practically for post-entry quarantine treatments than for treatment before shipment. In many post-entry situations, methyl bromide fumigation is the only technically and economically available and approved process to meet quarantine standards to allow importation. Ports often lack alternative treatment facilities and infrastructure. The cargos are often containerized and removal from the container is uneconomic. Methyl bromide fumigation may be ordered before the commodity can be released for distribution. Rejection or destruction of the cargo remains the default option if the treatment is not carried out.

MBTOC (2002) noted more than 300 individual alternatives approved for quarantine treatment of perishables and more than 70 approved as QPS treatments for durable commodities. These examples are often specific to a particular commodity and export trade and are drawn from several categories of alternatives (such as cold, heat, pest-free zones, systems approach, physical removal of pests, controlled atmospheres, pesticides, alternative fumigants, debarking, irradiation and combination treatments (MBTOC 2002; 2007)).

National Plant Protection Organizations (NPPOs) may publish listings of approved treatments for imports, with specifications varying according to phytosanitary requirements of receiving countries and pest risk. In many cases, methyl bromide fumigation may be specified as a quarantine treatment, but often there are also approved alternative treatments or processes given.

International Trade Manuals

Examples of manuals of approved quarantine treatments for international trade include:

USA – Animal and Plant Health Inspection Service (APHIS) Plant Protection & Quarantine (PPQ) manuals – http://www.aphis.usda.gov/import_export/plants/manuals/index.shtml
Australia – Australian Quarantine and Inspection Service (AQIS) Import Conditions database http://www.aqis.gov.au/icon32/asp/ex_querycontent.asp
New Zealand - Approved Biosecurity Treatments for Risk Goods Directed for Treatment - http://www.biosecurity.govt.nz/files/regs/stds/bnz-std-abtrt.pdf
Japan - Theory and Practice of Plant Quarantine Treatments (revised edition 2002) (JFTA 2002)

Some NPPOs also keep listings of treatments required to meet the quarantine and preshipment requirements of importing countries (e.g., AQIS's plant and plant product export conditions database named PHYTO (AQIS 2009)). These can include both methyl bromide and approved alternatives.

A listing of alternatives for various Quarantine uses was given in the IPPC recommendation (IPPC 2008) to its contracting Parties on preferential use of alternatives in place of MB, together with considerations affecting the choice of a phytosanitary measure to replace methyl bromide use. The listing is reproduced in Table 2-1.

Table 2-1. Examples of potential phytosanitary treatments to consider to replace or reduce use of methyl bromide

List of articles fumigated	Examples of potential phytosanitary treatments to consider to replace or reduce use of methyl bromide
Commodities	
Bulbs, corms, tubers and rhizomes (intended for planting)	Hot water, pre-plant quarantine soil sterilization (steam or chemical), pesticide dip, or a combination of these treatments
Cut flowers and branches (including foliage)	Controlled atmosphere (CO_2, N_2) + combination treatment, hot water, irradiation, phosphine, phosphine/carbon dioxide mixture, pyrethroids + carbon dioxide, ethyl formate + carbon dioxide
Fresh fruit and vegetables	Cold treatment, high-temperature forced air, hot water, irradiation, quick freeze, vapor heat treatment, chemical dip, phosphine, combination of treatments
Grain, cereals and oil seeds for consumption including rice (not intended for planting)	Heat treatment, irradiation, ethyl formate, carbonyl sulphide, phosphine, phosphine + carbon dioxide, controlled atmosphere (CO_2, N_2)
Dried foodstuffs (including herbs, dried fruit, coffee, cocoa)	Heat treatment, carbon dioxide under high pressure, irradiation, ethyl formate, ethylene oxide, phosphine, phosphine + carbon dioxide, controlled atmosphere (CO_2, N_2), sulfuryl fluoride, propylene oxide
Nursery stock (plants intended for planting other than seed), and associated soil and other growing media	Hot water, soil sterilization (steam or chemical e.g. methyl isothiocyanate (MITC) fumigants), pesticides dip, phosphine, combination of any of these treatments
Seeds (intended for planting)	Hot water, pesticide dip or dusting, phosphine, combination treatments
Wood packaging materials[7]	Heat treatment (contained in Annex 1 of ISPM No. 15). Further alternative treatments may be added in the future.
Wood (including round wood, sawn wood, wood chips)	Heat treatment, kiln-drying, removal of bark, microwave, irradiation, MITC/sulfuryl fluoride mixture, methyl iodide, chemical impregnation or immersion, phosphine, sulfuryl fluoride
Whole logs (with or without bark)	Heat treatment, irradiation, removal of bark, phosphine, sulfuryl fluoride
Hay, straw, thatch grass, dried animal fodder (other than grains and cereals listed above)	Heat treatment, irradiation, high pressure + phosphine, phosphine, sulfuryl fluoride
Cotton and other fibre crops and products	Heat treatment, compression, irradiation, phosphine, sulfuryl fluoride
Tree nuts (almonds, walnuts, hazelnuts etc.)	Carbon dioxide under high pressure, controlled atmosphere (CO_2, N_2), heat treatment, irradiation, ethylene oxide, ethyl formate, phosphine, phosphine + carbon dioxide, propylene oxide, sulfuryl fluoride
Structures and equipment	
Buildings with quarantine pests (including elevators, dwellings, factories, storage facilities)	Controlled atmosphere (CO_2, N_2), heat treatment, pesticide spray or fogging, phosphine, sulfuryl fluoride
Equipment (including used agricultural machinery and vehicles), empty shipping containers and reused packaging	Controlled atmosphere (CO_2, N_2), heat treatment, steam, hot water, pesticide spray or fogging, phosphine, sulfuryl fluoride
Other items	
Personal effects, furniture, crafts, artifacts, hides, fur and skins	Controlled atmosphere (CO_2, N_2), heat treatment, irradiation, ethylene oxide, pesticide spray or fogging, phosphine, sulfuryl fluoride

International Standards for QPS Treatments

Some international standards produced by the IPPC (called International Standard Phytosanitary Measures or ISPMs) relate directly or indirectly to phytosanitary (quarantine) processes that either use methyl bromide at present or avoid the need for QPS methyl bromide treatments.

The main ISPM that deals specifically with a major volume use of methyl bromide is ISPM 15, as revised (IPPC 2009b). The standard deals with the disinfestation of wood packaging material in international trade as a quarantine measure against various pests of wood and forests. The standard contains specifications for both heat treatment and methyl bromide fumigation. The standard recognises that methyl bromide is an ozone-depleting substance (p.5 of Appendix 4). It states, *"In the absence of alternative treatments being available for certain situations or to all countries, or the availability of other appropriate packaging materials, methyl bromide treatment is included in this standard."* (IPPC 2006, 2009). The recently revised ISPM 15 standard also encourages national quarantine authorities to promote the use of an approved MB alternative: *'NPPOs are encouraged to promote the use of alternative treatments approved in this standard'* (CPM-4 report, April 2009, p.11 of Appendix 4).

Other ISPM standards (www.ippc.int) relevant to methyl bromide treatments and alternatives are:

- ISPM No. 02 (2007) Framework for pest risk analysis
- ISPM No. 10 (1999) Requirements for the establishment of pest free places of production and pest free production sites
- ISPM No. 11 (2004) Pest risk analysis for quarantine pests including analysis of environmental risks and living modified organisms
- ISPM No. 14 (2002) The use of integrated measures in a systems approach for pest risk management
- ISPM No. 16 (2002) Regulated non-quarantine pests: concept and application
- ISPM No. 18 (2003) Guidelines for the use of irradiation as a phytosanitary measure
- ISPM No. 21 (2004) Pest risk analysis for regulated non quarantine pests
- ISPM No. 22 (2005) Requirements for the establishment of areas of low pest prevalence
- ISPM No. 24 (2005) Guidelines for the determination and recognition of equivalence of phytosanitary measures
- ISPM No. 26 (2006) Establishment of pest free areas for fruit flies (Tephritidae)
- ISPM No. 28 (2009) Phytosanitary treatments for regulated pests
- ISPM No. 29 (2007) Recognition of pest free areas and areas of low pest prevalence
- ISPM No. 30 (2008) Establishment of areas of low pest prevalence for fruit flies (Tephritidae)

Alternatives for the Main Methyl Bromide QPS Uses
Globally, the main categories of use of methyl bromide for QPS by volume (>300 tonnes a year) are:

- Fresh fruit and vegetables
- Grain including rice
- Soil, in situ, for production of propagation material
- Whole logs
- Wood and wooden packaging material

These main categories represent about 85% of the uses in 2007 for which detailed estimates are available at this time (i.e. excluding unidentified uses) and 70% of total reported consumption.

All of these categories have approved non-methyl bromide alternatives in at least some applications. Specific alternatives may not be available for a particular trade or situation because of the risk or presence of particular quarantine pests, lack of approval by the importing NPPO, or lack of registration or commercial supply of the particular treatment.

Fresh Fruit and Vegetables
This is a complex category comprising a large and diverse group of products. Very large volumes of perishable products are traded internationally each year (FAO 2009). The statistics on international trade and MB usage indicate that the vast majority of perishable products are traded without MB fumigation. The principal perishable commodities that tend to use MB for quarantine treatments are apples and pears, berry fruit, citrus, cucurbits, grapes, root crops, stone fruit, subtropical and tropical fruit, and some vegetables, as well as cut flowers, ornamentals and others (MBTOC, 2007 p.299). Quarantine treatments or procedures are considered essential in the cases where countries and commodities are hosts to specific pests that have quarantine significance to a specific importing country and are not found in the importing country and where the commodity being traded presents an unacceptable risk of the pest being introduced into the importing country.

Various alternative methods to MB have been developed in recent decades, in some cases to address product quality problems. The typical MB dosages required for successful QPS fumigation result in some perishables showing significant loss of marketability and quality (MBTOC 2007 p.299-300), such as reduced shelf-life. This acts as an incentive for the development and use of alternatives to QPS methyl bromide treatment. As described in previous MBTOC and TEAP reports (TEAP 1999, MBTOC 1994, 1998, 2002, 2007) there is a wide variety of non-MB treatments and procedures available, applied individually or in combination, which may be able to meet quarantine requirements depending on the pest in question, country of origin and quarantine security requirements of the importing country.

However, before quarantine treatments can be used, alternatives have to be approved case by case for specific commodities, pests, and countries, as explained in other sections of this report.

300+ Alternative Quarantine Treatments for Perishables
MBTOC (2002) recorded more than 300 alternative quarantine treatments for perishable commodities that had been approved by a National Plant Protection Organisation (national quarantine authorities) (MBTOC 2007, p.300) for some particular quarantine situation. This current study has identified many and diverse approved treatments. It provides examples of alternative quarantine treatments and procedures that have been approved by national quarantine authorities for the list of fresh fruit and vegetables listed in Table 6-1 and Annex 2. Approved alternatives include cold treatments, various types of heat treatments, heat + controlled atmospheres, pesticide dips or sprays, wax coating, pest removal (e.g. by brushing), alternative fumigants, irradiation, crop production in areas free from quarantine pests, the systems approach, and inspection procedures. Examples for particular perishable commodities are summarised in Table 6-1 and given in more detail in Annex 2. Technical descriptions of these alternatives can be found in previous MBTOC reports (e.g. MBTOC 2002, pp.273-318; MBTOC 2007, pp.306-315). For most of the commodities listed in Table 6-2, two or more different types of alternatives have been approved by various quarantine authorities for specific quarantine situations. Cold, heat and irradiation treatments appear to be applicable to the widest range of commodities at present.

There is a wide variety of pests of quarantine significance, varying according to origin and country of destination. These include tephritid fruit flies, mealybugs, thrips, aphids, mites and other groups shown in Table 2-3.

In many cases, the approved treatments apply to a particular situation, i.e. a commodity with particular pest(s) from a certain country or region and a specific quarantine concern of the importing country (MBTOC, 2007), as illustrated in Annex 2. Each approved treatment may be applicable to just one or several species of fruit fly, for example. However, in some cases an approved treatment covers many species, such as “external feeders” and “insects,” as shown in Table 2-3.

Categories of Alternatives for Perishables
Alternatives for perishables (e.g. fresh fruits, vegetables, cut flowers) can be grouped by process into three classes:

- Pre-harvest practices, including systems approaches
- Non-chemical treatments
- Chemical treatments, including fumigation

Non-chemical treatments kill pests by exposure to changes in temperature and/or atmospheric conditions, or high energy processes such as irradiation and microwaves, or physical removal using air or water jets. Often a combination of these is required to kill particular quarantine pests or pest complexes because they can tolerate a single treatment.

Although a number of treatments have been approved, actual use of these treatments is not well documented (MBTOC 2007, p.300). The QPSTF did not collect statistics on the specific commercial adoption and use of QPS alternatives on particular categories of fruit and vegetables. Some of the approved treatments listed in Table 6-2 may not be used at all in commercial practice, while others are used to a significant extent. For example, the non MB systems approach required for Hass avocado exported from Mexico (Michoacán region only) to the USA appears to be well used, according to FAO statistics (http://faostat.fao.org). Mexico exported a total of about 310,260 tonnes of avocado in 2007 (value $US 620 million), and much of this was imported by the USA, indicating that this quarantine procedure is used for a significant volume of product. An APHIS document also reported on the efficacy of the Mexico/Michoacán avocado procedure in commercial practice (which does not use MB), stating that "*In 6 years of experience, the surveys, inspections, and fruit cuttings have not detected the presence of any insect pests in the importation of Mexican Hass avocados*" (APHIS 2004, p.8).

Alternative treatments for perishable products may be carried out in the country of origin, or in-transit in some cases, or in the importing country as outlined below. However, although for reasons of practicality (see below), fumigation with MB may at present be the only available treatment in lieu of destruction or rejection of the consignment if infestation by quarantine pests is detected at the port of entry.

Treatments in the country of origin: Some of the approved alternative methods, notably systems approaches, pest free areas and pre-export inspection requirements, can only be carried out in the country of origin. For some important quarantine pest species such as fruit flies and codling moth, some importing countries require that infestible perishable commodities undergo a mandatory treatment or procedure prior to export. Exporters sometimes prefer to carry out quarantine treatments in the country of origin for economic reasons. The cost of materials and labour for quarantine treatments can be lower in the exporting country, particularly if the destination country is a non-A5 country with higher labor costs or high charges for port demurrage. Quarantine MB fumigations in the Philippines, for example, were reported to be $US 20–80 if carried out prior to export compared with $1,500–2,000 if carried out in destination countries (MLF 2004, prices in 2004 dollars).

In many cases fixed facilities are needed for carrying out treatments (e.g. heat, cold, controlled atmospheres) and it can be cheaper for the exporters to locate and operate the facilities in the country of origin than in the importing country, i.e. it is often more efficient to treat the entire commodity at the point of origin than to treat it after it has been dispersed to several different ports. Taiwan, for example, has 4 vapour heat treatment facilities and pack houses which have been approved by the Australian quarantine authorities for mangoes exported to Australia, while the Philippines has 5 registered treatment facilities for mango (AQIS 2009).

For certain treatments such as MB and heat, there is a product quality cost, however, for treating perishables before transit since the earlier treatment significantly cuts shelf-life of the treated commodity compared to treatment after transit. On the other hand, cold treatments and controlled atmospheres can improve the shelf-life and quality of perishable commodities (such as flowers and fruit) if carried out prior to export.

For perishable products, pest control based on pre-harvest practices, as part of the systems approach as described in ISPM No. 14, must include cultural techniques leading to pest reduction, must have an agreement on the area of any pest-free zones, and be subject to inspection in order to receive certification. In these cases, regulatory approval depends on a number of factors including knowledge of the pest-host biology, evidence of commodity resistance to the pest, trapping and field treatment results, monitoring of pests and diseases, and careful documentation.

In-transit treatment: In some cases the approved alternative treatments (e.g. cold, controlled atmospheres) are allowed to be carried out while commodities are being transported to their destination in a truck, shipping container or ship hold that has the relevant equipment. The quarantine authorities in the USA, for example, have approved the equipment installations in a number of ships and in hundreds of shipping containers for in-transit cold treatments (CPHST 2009b, 2009c). For example, citrus shipped from Spain to the US can be treated by cold treatment in transit.

Treatments on arrival in the importing country: When products arrive in an importing country and are found to need a quarantine treatment, MB tends to be the prevalent treatment in a number of countries, due to logistic issues such as a lack of rapid pest identification facilities and lack of alternative treatment facilities at ports of entry. Quarantine authorities in the USA, for example, have approved a total of about 116 quarantine treatment facilities for imported products in 28 states (primarily for MB fumigation). This total includes seven heat treatment facilities[1] located in five states, and eight cold treatment facilities located in one state only (APHIS 2008 ab). So in many US states, only MB and phosphine facilities appear to be available at present for carrying out quarantine treatments on imported perishable products (APHIS 2008ab).

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1 Some of these heat facilities are small and may not be suitable for perishable products. These 7 heat facilities are intended for imported products only. This number does not include the heat facilities approved for ISPM-15 treatments in the USA.

Table 2-2: Examples of alternative non-MB quarantine treatments approved by some national quarantine authorities for fresh fruit and vegetables (listed by commodity) for specific quarantine situations involving particular importing and exporting countries

Perishable commodities	Examples of alternative quarantine treatments or procedures						
	Cold	Heat	Chemical	Irradiation	Pest free areas	Inspection	Systems approach
Fruit (many types)			CHM		PFA		
Vegetables, many types			CHM		PFA		
Apple	CT	CAT			PFA	INS	SYS
Apricot	CT				PFA	INS	
Avocado	CT				PFA, SA	INS	SYS
Blueberry	CT		CHM			INS	
Breadfruit			SWB				
Cape gooseberry	CT						
Carambola	CT			IRR			
Cherimoya			SWW				
Cherry	CT	CAT					SYS
Citrus	CT	HTF			PFA		
Clementine	CT	VHT					
Durian, other large fruits			SWB				
Eggplant		VHT		IRR			
Ethrog	CT						
Garlic					PFA		
Grape	CT		FUM				SYS
Grapefruit	CT	VHT			PFA	INS	
Guava				IRR			
Horseradish roots		HWT					
Kiwi fruit	CT						
Kumquat	CT	HTF					
Lemon	CT	HTF					
Lime		HWT, HTF	SWW				

Perishable commodities	Examples of alternative quarantine treatments or procedures						
	Cold	Heat	Chemical	Irradiation	Pest free areas	Inspection	Systems approach
Litchi (lychee)	CT	HTF, VHT		IRR			
Longan	CT	HWT		IRR		INS	
Loquat	CT						
Mandarin	CT						
Mango	CT	HWT, VHT		IRR	PFA		
Nectarine	CT	CAT					
Orange	CT	HTF, VHT					
Ortanique	CT						
Papaya		HTF, VHT					
Passion fruit			SWW				
Peach	CT	CAT			PFA	INS	SYS
Pear	CT					INS	SYS
Pepper (bell)		VHT			PFA	INS	
Persimmon	CT						
Pineapple		VHT		IRR			
Plum, Plumcot	CT						SYS
Pomegranate	CT				PFA	INS	
Rambutan		HTF, VHT		IRR			
Squash		VHT					
Tangerine	CT	HTF					
Tomato		VHT					
Zucchini		VHT					

Key to table:

CAT Forced moist air or vapour warm air with controlled atmosphere treatment, e.g. 1% oxygen, 15% CO_2.
CHM Chemical dip or spray, e.g. specified fungicide, acaricide or nematicide, other than MB.
CT Cold treatment
FUM Fumigant other than MB, e.g. phosphine, sulfuryl fluoride.
HTF High temperature forced air treatment
HWT Hot or warm water treatment
INS Inspection
IRR Irradiation
PFA Approved pest-free production area
SA Systems Approach comprising measures such as pest free areas, trapping, field sanitation, registered packhouses, screened storage etc.
SWB Soapy water + brushing
SWW Soapy water + wax
VHT Vapour heat treatment

Table 2-3: Examples of alternative non-MB quarantine treatments used alone or in combination approved by national quarantine authorities for fresh fruit and vegetables (listed by pest group) for specific quarantine situations involving particular exporting and importing countries

Categories of pests controlled by approved treatments	*Examples of alternative quarantine treatments or procedures*						
	Cold	Heat	Chemical	Irradiation	Pest free area	Inspection	Systems approach
External feeders, surface pests		HWT	SWB			INS	
Fruit borers	CT					INS	
Fruit flies	CT	CAT, HTF, HWT, VHT		IRR	PFA	INS	SYS
Fruit moths (a)	CT	CAT			PFA	INS	SYS
Fungi (b)			CHM		PFA	INS	
Insects			FUM	IRR		INS	
Mealybugs	CT	HWT			PFA	INS	
Mites (c)			SWW, CHM			INS	SYS
Nematodes		HWT			PFA	INS	
Spiders			CHM			INS	
Weevils	CT	VHT			PFA	INS	
Unspecified quarantine pests	CT	VHT, HTF	CHM		PFA	INS	

(a) Including codling moth, false codling moth, light brown apple moth. (b) Including citrus black spot, fruit rusts. (c) Including spider mites, false spider mite.

Alternatives Under Development for Perishables

Fresh fruit and vegetables comprise a difficult category for development of quarantine treatments in order to avoid or minimise chemical injury, quality deterioration or phytotoxicity. Adverse effects vary according to the country or area of production, the varieties involved and other factors. Additionally, some types of perishable commodities are directly consumed without processing or cooking and therefore, tests such as residue analysis to ensure food safety are required. Mortality tests and chemical injury tests are presently being conducted or planned in Japan; chemical injury tests mainly consider methyl iodide, phosphine and sulfuryl fluoride. In particular, methyl iodide is expected to exhibit toxic properties that are similar to those of methyl bromide given that their chemical composition is almost equivalent. Phosphine fumigation at 1.5 g m-3 for 24h at >15°C is registered as a quarantine treatment for Japanese pear. Mortality tests for fresh fruits are in progress to evaluate control of leaf miners, spider mites and mealybugs with a mixture of ethyl formate + carbon dioxide.

Until recently phosphine, generated from aluminium phosphide preparations, was not used for perishable commodities because ammonia contaminants released from the formulation damaged some perishable goods (Horn and Horn 2004). However, experts in Chile have developed treatments of pure phosphine at low temperature (i.e. cold-storage temperature, or 1.5 - 15 ºC) which have been found to control key fruit pests, such as mealybugs, *Pseudococcus* spp; apple moth, *Cydia pomonella*; eulia, *Proeulia spp*; fruit tree weevil, *Naupactus xanthographus*; mediterranean fruit fly, *Ceratitis capitata*; fruit fly, *Rhagoletis* spp, *Bractocera* spp, *Anastrepha* spp; and *Thrips* spp., without causing damage to the fruit (Horn and Horn 2004). This pure phosphine treatment has been adopted commercially as a MB alternative for quarantine (and non-quarantine) pests for fruit exports from Chile to Mexico, Iran and other countries. New Zealand has recently registered pure phosphine as a postharvest pesticide for kiwifruit (for armoured scales and mealy bugs) and studies are underway to gain approval for quarantine use (Horn 2009). USDA researchers recently tested pure phosphine at cold temperatures as a MB alternative, and found there was no damage to artichokes, white-flesh peaches, and white-flesh nectarines (USDA 2008, p.9). USDA researchers also demonstrated that pure phosphine is effective in controlling western flower thrips without causing damage to commodities such as strawberries, lettuce, broccoli and asparagus (USDA 2008, p.9).

Grain, including Rice

Methyl bromide fumigation continues to be used for preshipment treatment of cereal grains where logistical constraints at point of export or importing country specifications preclude the use of phosphine, the principal accepted fumigant alternative, or where methyl bromide treatment is specified by regulation, or for treatments against certain specific regulated quarantine pests. Methyl bromide fumigation may be the treatment of choice or the only approved and available treatment for the situations where a quarantine treatment is required, though it is acknowledged that it may not be ideal for this purpose when it causes some damage to the commodity.

There are different alternative treatments of choice for grains to meet appropriate QPS standards, depending on whether the treatment is officially required by national authorities for normal and widespread insects that attack or are associated with grain in storage and transport (i.e. pre-shipment), or for control and elimination of specific regulated quarantine pests.

Export cereal grains, such as rice and wheat, are prone to infestation by a number of cosmopolitan grain pests that cause damage when in storage and are unacceptable to modern market standards. Most of the MB fumigations that target these pests are non-QPS treatments, falling outside the Protocol's definition of QPS. However, these pests are also the main target of the preshipment treatments that are required by official regulations of some exporting countries or by official requirements of some importing countries. Export cereal grains, similar products and associated packaging from some locations may also be subject to quarantine treatments against specific insect pests, notably khapra beetle (*Trogoderma granarium*), or contaminants such as specific snails (e.g.. *Cochlicella* spp.) or seed-borne diseases such as karnal bunt (*Tilletia indica*).

Alternatives for Preshipment Treatment on Grain

There are well known, standard processes for protection and disinfestation of stored grain in storage and transport, capable of delivering grain (either bagged or in bulk) to an export point in a pest-free condition without recourse to methyl bromide fumigation (e.g. see MBTOC 2007). The choice of alternative is dependent on the commodity or structure to be treated, the situation in which the treatment is required, the accepted level of efficacy and the cost and the time available for treatment. Some alternatives (e.g. some fumigants, heat treatment) may be implemented as 'stand alone' treatments to replace methyl bromide in certain situations. Others may be used in combination to achieve an acceptable level of control.

Preshipment treatments in general are aimed at a lower standard of pest control than quarantine. While quarantine treatments lead to a commodity free of regulated quarantine pests, preshipment treatments only require the consignment to be 'practically free' of pests. This lower level of security gives a wider choice of alternatives, with reduced requirements for efficacy testing.

These processes can theoretically avoid the need for any further treatment against infestation at the export port. In practice, consignments may be brought to the export point in infested condition. Also, particularly in humid, tropical situations, there is often a high invasion pressure from pests at the export point. As a result, an insecticidal process, usually fumigation, must be used to ensure the grain meets the exporter's or importer's official regulations for lack of infestation.

Alternatives to methyl bromide fumigation for preshipment of cereal grains, including rice, vary with situation, particularly the required speed of action. In some export situations, there is sufficient capacity at the port, to allow slower acting alternative treatments to be used easily, with treatment times of 7 days or more for full effectiveness. Phosphine fumigation is in widespread use for this purpose, for both bagged and bulk consignments. Controlled atmosphere technologies have some usage at present (e.g. Clamp and Moore 2000), but have potential for much more widespread adoption. Dichlorvos treatment, where permitted, also will provide pest-free grain up to inspection standards.

In many export situations, a high throughput is required, where there is limited space at the port for treatments and where demurrage costs on waiting vessels is high. Typical turnaround times for methyl bromide for a shipment can be 24-48 hours, a time that has to be accommodated in the organization of the export consignment under preshipment treatment.

More rapid treatments would be welcomed in many export situations, as these would minimize delays associated with handling the export consignment, such as associated costs and grain handling limitations. At this time there are no agreed, widely available and approved preshipment treatments that will match the treatment speeds of large consignments that can be achieved with MB fumigation, though there are several in advanced stages of commercialisation and the regulatory approval process. The fumigants sulfuryl fluoride, cyanogen and carbonyl sulphide, and synergised ethyl formate all have potential to give similar treatment times and throughputs as methyl bromide (MBTOC 2007). Sulfuryl fluoride fumigation is restricted by availability and registration of the fumigant to only a few countries at this time, but now is in routine use as an alternative to methyl bromide for preshipment treatment of grain in certain countries, such as Australia.

Irradiation has been used for preshipment disinfestation of grain (Zakladnoi *et al*. 1982) and heat treatments have been demonstrated at moderate rates of throughput (150 tonnes per hour (Thorpe *et al*. 1984)). Both systems require very substantial infrastructure if they are to match treatment speeds provided by fumigants, including methyl bromide.

Some importing countries may specify fumigation at point of export as a pre-shipment treatment, with indications as to what treatments are acceptable. Typically where methyl bromide is specified as one treatment, phosphine fumigation may be specified as an alternative. However, several countries specify use of methyl bromide as the only acceptable QPS treatment of imported grain from specified exporters, even though well-conducted phosphine fumigation may be expected to deliver the same technical outcome as methyl bromide treatment.

Treatment, after loading, of bulk or bagged grain in ships with phosphine after loading may potentially replace some current preshipment uses of MB. However, this may be interpreted as falling outside ‘preshipment’ timelines and may not meet regulatory requirements of some exporters and importers who require grain to be practically pest-free before loading. Phosphine treatments may be conducted at the dockside, in lighters or barges prior to loading a ship, or in the ship after loading and before sailing. In suitable ships, in-transit phosphine treatment gives an effective post-export treatment.

International Maritime Organisation (IMO) recommendations on safe use of pesticides in ships and shipping containers describe the safe use of both phosphine and methyl bromide at port and in-transit (IMO 2008 ab).

The International Maritime Organisation (IMO 1996) specifically recommends that cargoes should not be fumigated in ships with MB prior to sailing due to the risks resulting from the difficulty in ventilating the cargo effectively. As an alternative to methyl bromide, for safety and efficacy reasons, in-transit treatment with phosphine is restricted to specially-designed bulk carriers, tanker-type vessels and other ships where the holds are gastight or can be made so (Semple and Kirenga, 1997). In addition, equipment must be installed to circulate the phosphine through the cargo mass (Watson *et al.*, 1999). The circulation equipment ensures that the gas penetrates throughout the load and can be aired from the load prior to unloading. In-transit treatment of bulk grain is in widespread use, potentially avoiding the need for methyl bromide treatment prior to shipment where import and export regulations permit.

Alternatives for Quarantine Treatments on Grain

Many countries have strict quarantine regulations on grain and other durables originating from countries where khapra beetle occurs. Typically, only methyl bromide treatment is specified against this notorious pest, requiring twice the normal dosages for stored product disinfestation often with an extended exposure period. For instance, cereal products from khapra beetle areas for import into Australia require 80g m-3 for 48 hours at 21°C with an end point concentration at 48 hours of 20g m-3 (ICON 2009).

The USDA PPQ Treatment Manual (USDA 2009) contains many treatment schedules specific to khapra beetle. Schedule T307-a refers to various treatment schedules for commodities and transport vehicles found to be infested with khapra beetle for post-entry quarantine treatment. Heat treatment at a high temperature and prolonged exposure (7 minutes at 65.5°C) is given as the only approved alternative and only to be used when specifically authorized.

Heat treatment appears to be a good alternative treatment against khapra beetle, with potential as a quarantine measure. Despite its tolerance to quite high temperatures at around 41°C, it is quite susceptible to higher temperatures, more so than some common storage pests such as *Rhyzoperta dominica*. There is a surprising quantity of data available to substantiate this. Much of it is older, but of good quality. For instance, Husain (1923) studied heat disinfestation of wheat from khapra larvae.

Pupae of *T. granarium* are the most heat tolerant stage, requiring 16 hours at 50°C or 2 hours at 55°C for '100%' kill, while other stages are eliminated in less than 2 hours (Mookherjee *et al*., 1968). *R. dominica* requires in excess of 24 hours for complete kill at 50°C, 5 hours at 51°C and 10 minutes at 55°C. Battu *et al*. (1975) found LT_{95} for diapausing and non-diapausing larvae to be 7.4 and 3.0 hours respectively at 50°C. Lindgren *et al.* (1955) noted a slight dependence of time to complete kill an ambient relative humidity with treatment at high humidities taking slightly longer. At 55°, 75% r.h., 95% mortality was obtained after 8 and 15 minutes with 4th instar larvae and pupae respectively. Wright *et al*. (2007) investigated heat treatment of *Trogoderma variabile,* showing it to have similar response to heat as *T. granarium*.

T. granarium is usually quite susceptible to phosphine (e.g. Hole *et al*. 1976). Phosphine fumigation at one time appeared to be a potential alternative to methyl bromide against this pest, but it is probably no longer so, with the development of high levels of phosphine resistance in the Indian subcontinent.

Tests to quarantine standards with alternative fumigants, such as sulfuryl fluoride, would result in a reduction in the use of methyl bromide.

Some winter wheat fields in Texas were infected with Karnal bunt disease, *Tilletia indica*, in 2001. When infected grain was harvested and transferred to storage bins, the bins and grain handling equipment became infected. MB fumigation of emptied contaminated storage bins requires a high dosage (240 g m^{-3}) for 96 hours to meet quarantine standards. Steam heating to a point of runoff in bins also is an effective alternative to MB providing surface temperatures reach 77°C (Dowdy, 2002). Microwave technology has recently been reported as effective in controlling *Tilletia indica* teliospores (karnal bunt of wheat) in 10 seconds compared to 96 hours using MB (Ingemanson, 1997).

Alternative treatments to methyl bromide are needed for various snails of quarantine significance (e.g. *Achitina fulica, Cernuella spp., Theba pisana*). Methyl bromide fumigation is usually the only approved quarantine measure for these pests when associated with grain shipments. Other processes, including HCN and CO_2 fumigations, may be more effective (e.g. Cassells et al. 1994), but are not approved.

Alternatives under Development for Grain

Japan imports about 30 million tonnes of grain (including for example wheat, maize and soybean). The quantities of MB used for grains in Japan are larger than for any other category except whole logs (PPS, 2007). Phosphine (PH3) fumigation using aluminum phosphide tablets has been introduced as part of the plant quarantine treatment schedule in Japan (MAFF, 1971). This treatment has now, however, been adopted for controlling Sitophilus species because the pupal stage of Sitophilus granarius (a regulated quarantine pest for Japan) could not be killed completely at the dosage rates and fumigation conditions used in commercial quarantine fumigation (Mori and Kawamoto, 1966). On the other hand, sulfuryl fluoride has higher efficacy against pupal stages of several stored product insects, although the egg stage is the most tolerant (Furuki et al. 2005; Bell et al. 2003). Fumigating with a mixture of PH3 and SF gas kills all stages of Sitophilus species, using the good properties of both fumigants. Tests with mixtures of phosphine and sulfuryl fluoride (PH3 + SF) are in progress in Japan.

Alternatives for Preplant Soil Use – Propagation Materials

The use of methyl bromide for soils falls under three categories, as can be seen from Parties' responses to Decision XX/6:

1) treatment of soil or substrate as a commodity
2) treatment of soil to eradicate quarantine pests
3) treatment of soils in situ as a preplant fumigation

Treatment of Soil as a Commodity

Soil or substrates as commodities may be treated with MB to ensure pests are controlled upon export to another country. Other commodities, when shipped between countries, may be required to be essentially free of soil or treated with MB to ensure any residual soil on the commodity is fumigated, e.g. flower bulbs. For example, this use is reported by Malaysia, with a usage of 5.05 tonnes for 2007 in this category. Used equipment with soil attached may be fumigated with methyl bromide against quarantine pests, where steam treatment is unsuitable. Several Pacific Island countries import bulk soil and aggregate that is fumigated against pests, weeds and diseases at export. The quantity of MB used for this use is small, estimated at less than 100 tons annually.

Treatment of Soil in Situ to Eradicate an Exotic Quarantine Pest

Several cases exist worldwide where an exotic pest has invaded a restricted region within a country and is under official control. The control of these pests often specifies MB fumigation or an alternative that prevents further spread of the pest to other regions. MB as a soil treatment is often the fumigant of choice. For instance, the potato cyst nematode *Globodera pallida* is a quarantine pest in the United States with occurrence limited to the state of Idaho. Regulations 301.86 to 301.89 impose restrictions on the movement of materials from the state and designate quarantined areas within the state (Federal Register Vol 73 No. 177, Sept 11, 2008; USDA 2007). An eradication program presently covers a total of eight fields comprising approximately 445 ha, which are fumigated with MB once a year, usually in the spring. In both 2007 and 2008, 217 tonnes of MB were used for this

purpose. The fumigation is followed by a Telone/chloropricrin fumigation 6 months later (Vick, 2009, pers. comm.; USDA 2007). The program is expected to take several years to complete.
In a similar quarantine situation, 4.5 tonnes of MB was used to eradicate golden nematode (*Globodera rostochiensis*) from an infested area in New York state in 2008.

These examples of treatment of soil in situ against a quarantine pest for purposes of eradication of that pest are similar to that in other countries, i.e. Australia. Methyl bromide was used prior to 2006 as a treatment of soil to control and eliminate branched broomrape (*Orobanche* sp), an exotic quarantine pest (parasitic plant) of limited distribution within Australia. This use of MB has since been discontinued as the pest was not effectively controlled and other products are now used to limit further spread.

Preplant Fumigation of Soils for Nursery Plants and Turf
Preplant fumigation of soils with methyl bromide to produce plants for propagation or turf is distinct from treatments of soil to eliminate recognised quarantine pests either in soil transported as a substrate or treated in situ. The key difference is that preplant soil use is often applied many months prior to harvest of the plants and treatment is used to minimise spread of common endemic pests. In contrast, treatment of soil or substrate that is either imported or exported as a commodity (to grow plants in) is sometimes fumigated with MB as a quarantine measure to ensure freedom from a pest not found in the region to which it is exported.

A very large amount of research and experience has been devoted to the development and adaptation of alternatives to methyl bromide for pre-plant soil fumigation (MBTOC, 2007, TEAP, 2008; 2009). A statistical analysis undertaken by MBTOC for expert assistance with CUNs was conducted to evaluate alternatives to MB for preplant fumigation (Porter *et al*, 2006). It mainly concentrated on production of strawberry fruit and tomatoes. Analyses from strawberry fruit trials showed that a large number of alternatives used alone or in various combinations had mean estimated yields which were within 5% of the estimated yield of the standard MB treatment (MB/Pic 67:33). Of these, a number of alternatives led to results that were comparable to MB/Pic. These included chloropicrin alone, 1,3-dichloropropene (1,3-D) + chloropicrin, 1,3-D/Pic + metham sodium and methyl iodide + chloropicrin, which was registered in the majority of US states in 2008 (excluding California) and which is undergoing review for registration in several countries. As shown below, these alternatives are being adopted as effective alternatives for nursery uses in many non A5 countries (MBTOC, 2007; TEAP, 2008; 2009) that once used MB for nursery uses. Alternatively, substrates using soilless mixes are proving very effective in replacing MB for many nursery uses.

Presently, there is widespread adoption of these and other alternatives in many countries, showing equal effectiveness to methyl bromide (MBTOC, 2007; TEAP, 2008; 2009).
Table 2-4 gives the range of plant types that are grown as propagation material with the aid of methyl bromide in the US (2004 data).

__Table 2-4. Production of various types of propagation material in the US with associated methyl bromide usage (2004 data)__

Propagative material – source	**Tonnes of MB used in US (2004**
Bulb growers	261
California deciduous nurseries	127
California rose nurseries	136
Forest nurseries	174
Strawberry nurseries	463
Turfgrass (sod)	266
Western raspberry nurseries	25
Misc.	24
Total	**1476**

Source: US Response to Decision XVI/10, rounded to nearest tonne

The production of propagation materials is subject to high health standards and often certification requirements, which are readily achieved with methyl bromide, applied to production beds. In the case of strawberry runners for example, MB is used to meet the certification standards for strawberry runner stock. The certification typically specifies a low tolerance of particular pests and diseases. Since a single strawberry runner grown in year one can expand to several million runners over three generations in soil, the detrimental impacts of pests in an early generation of the multiplication process is of particular importance. The same is true for stock plants used for producing cuttings of many ornamental plants.

In spite of these requirements, there are several measures accepted as alternatives to methyl bromide for production of propagative material. Methyl iodide and 1,3-D either alone or in combination with chloropicrin, are proving extremely effective in several countries and for several US nursery sectors (e.g. Kabir *et al.*, 2005). A recent version of NIPM Item #7 'Approved treatment and handling procedures to ensure against nematode pest infestation' lists 1,3-D and methyl iodide aside from methyl bromide, as alternative treatments to achieve certification requirements related to nematode control (CDFA, 2009), although methyl iodide is not currently registered in California.

Studies have shown that plants grown in soils treated with MB fumigation carry pathogens which are known to occur in the regions to which they are exported (De Cal, *et al.*, 2004; 2005). Often, the levels of pathogens are lower than the surrounding levels in soils at the site where they are grown, due to the presence of established endemic pathogens.

Alternatives for Strawberry Runners

1,3-D/Pic and Pic alone have totally replaced the use of MB in the Spanish strawberry runner industry (García-Méndez *et al.*, 2008; López-Medina *et al.*, 2007; De Cal *et al*, 2004). Strawberry production from transplants fumigated with MB alternatives was evaluated in Spain (López-Medina *et al.*, 2007); results indicated that treatments with 1,3-D alone or 1,3-D/Pic are efficient alternatives to MB for high elevation strawberry nurseries. These alternative fumigants are registered and available in regions producing strawberry runners in the US.

Preplant soil treatments with MI/Pic, Pic followed by dazomet and 1,3-D/Pic followed by dazomet were shown to be potential alternatives to MB for strawberry runner production in California (Kabir *et al.*, 2005). MI/Pic is now being adopted by ths strawberry runner industry in the SE United States (USA 2009 CUN for strawberry runners). Nursery yields and subsequent fruit yields in California were found to be similar to those obtained with MB when treated with MI/Pic, or 1,3-D followed by dazomet and chloropicrin followed by dazomet, although economic considerations influenced adoption (Fennimore *et al.*, 2008).

Alternatives for Forest Nurseries

Research on forest nurseries reports chloropicrin alone in combination with herbicides - when weeds pose problems - or 1,3D/Pic - when there are nematodes present - as effective alternatives for MB used as a QPS treatment (South 2008). Methyl iodide has been found to provide control of pathogens and weeds that is not significantly different to that achieved with MB (Enebak, 2006); chloropicrin alone (South, 2007; 2008); 1,3-D/Pic (South, 2008); 1,3-D /Pic/metham sodium (South, 2008); metham sodium + Pic (Cram *et al.*, 2007); and dazomet (Muckennfuss *et al*. 2005; Enebak *et al*., 2006). Pic and metham when used in conjunction with barrier films (LPBF) may provide an effective technical alternative. Enebak (2007) found that with LPBF, use rates of MB can be significantly reduced.

Alternatives for Other Kinds of Propagation Materials

Further successful trials have been reported on rose nurseries (Hanson *et al.* 2008; 2009). MI/Pic, 1,3-D and 1,3-D/ Pic with high density polyethylene (HDPE) plus 1,3-D/Pic with VIF appear to provide weed control similar to MB in perennial tree nurseries (Shrestha, *et al*., 2008, Schneider *et al*., 2009).

Non-chemical Alternatives for Nurseries

An alternate approach to chemical soil treatments is the production of nursery stock in bags or containers of different types, using soilless substrates (MBTOC, 2007). Substrates are becoming increasingly adopted as they avoid the need for methyl bromide in many countries (Walter *et al.*, 2008). Strawberry plug plants were found to be a viable alternative to soil fumigation, as long as specific requirements associated to this technology are met (Durner *et al*, 2002; Sances, 2005). Maintaining good hygiene levels for plug plants is essential to their further expansion. Contamination can produce outbreaks of diseases, especially some airborne diseases which can proliferate under the controlled conditions of plug production.

Production systems where this approach is economically feasible and allows for the production of high quality products have been identified. In Japan for example, a simple, economically feasible system using trays filled with substrate is proving particularly useful for the production of strawberry runners. Various materials are used as substrates (e.g. rock wool, peat moss, rice hulls, and coconut husk and bark) and can be reused after sterilising with solar heat treatment or hot water (Nishi and Tateya, 2006).

Steam is in wide use for treating used substrates recycled for use for the production of propagation materials in Europe (EC Management Strategy, 2008) as well as in other countries around the world, including developing countries producing propagation materials which are subject to certification requirements.

Alternatives Under Development in Nurseries

DMDS + chloropicrin produced promising results in the forest nursery sector, although the former is not registered (Weiland *et al.*, 2008; Quicke *et al.*, 2007, 2008). Methyl iodide is gaining more widespread acceptance with new registration pending in several countries (TEAP, 2009).

Whole Logs
Logs, timber and wooden materials (e.g. sawn timber, wooden packaging materials) are notorious for their ability to carry a variety of pests of quarantine significance. Some of these pests potentially attack forests and amenity trees (standing timber), while others can attack timber in furniture, buildings and other structures. Targets of methyl bromide fumigation may be insects that infest green and dry wood (Table 6-5), nematodes (particularly pinewood nematode, Bursaphelenchus xylophilus) and some fungal pests of wood, notably oak wilt fungus (Ceratocystis fagacearum). Fumigations may also be carried out to eliminate hitchhiker pests of quarantine significance, including pest insects and snails.

Some wood inhabiting fungi that need to be controlled, usually for quarantine purposes, are: *Antroida carbonica, Ceratocystis fagacearum, Gloeophyllum sepiarium, Lentinus lepideus, Lenzites sepiaria, L. trabea, Postia placenta* and *Serpula lacrimans.*

Table 2-5. Groups of wood insects containing species of quarantine importance that are targets of methyl bromide fumigation. Modified from ISPM15 (IPPC 2006)

Pest family	**Common name**
Anobiidae	Wood borers, woodworms
Bostrichidae	Powder-post beetles
Buprestidae	Jewel beetles
Cerambycidae	Longicorn beetles
Curculionidae	Weevils
Isoptera	Termites, white ants
Lyctidae	Powder-post beetles
Oedemeridae	False blister beetles
Scolytidae	Bark beetles
Siricidae	Wood wasps

Alternatives for Logs

Methyl bromide is the most widely used fumigant for logs but does have some limitations, i.e. limited penetration, particularly across the grain and into wet timber. Most arthropods associated with timber are susceptible to methyl bromide but much higher dosages are required to kill fungi (e.g. see Rhatigan *et al.*1998). Green logs are problematic to treat due to the high moisture content (80%), presence of bark (very adsorbent), size, and large volumes.

Treatments of logs may need to be rapid, such as at point of export or import, to avoid charges and congestion at ports associated with occupying restricted port area for the treatment. Where quarantine treatments can be applied outside port areas, such as prior to export or in-transit, slower systems can be used. Many pests of quarantine significance, which attack green wood, do not reinfest dry and debarked wood.

There is active research in progress to develop alternatives for logs but gaining the required efficacy data is very difficult as laboratory rearing has not yet been achieved to the numbers required, most insects are seasonal, and the commodity is large and variable.

Phosphine in transit on those parts of the shipment carried under deck is the only commercially used alternative currently available for under bark pests. China has approved a specific treatment schedule for sulfuryl fluoride on logs for fumigation in Germany and other countries prior to export.

Methyl iodide (MI)/CO_2 and the methyl isothocyanate (MITC)/sulfuryl fluoride mixtures have been registered in Japan but not yet used commercially. Cyanogen shows promise but is yet to be registered or used commercially.

Research on alternatives for logs evaluating the efficacy of MI and MITC/SF mixtures have been completed in Japan and both treatments are under the process of inclusion under the relevant regulations. However, instructions or procedures for conducting gas measurements and safety devices to protect fumigators from gas exposure still need further work.

As logs are a high volume, and comparatively low value commodity and are shipped long distances, the trade is very price sensitive to changes in freight costs, exchange rates and treatment costs. What may be an economic treatment for fruit may not be economic for logs. Non fumigant methods such as heat, microwaves and irradiation are normally cost prohibitive for logs.

Specific QPS alternatives for logs are discussed below, followed by discussion of some processes under development.

Reduction in Fumigation Rate for Logs

Treatment specifications for logs have not been harmonised worldwide and schedules vary with country of import and target pest. For example, New Zealand's use could be reduced by 53 tonnes per annum by reducing the fumigation rate from 120 to 80 g m^{-3}, as data show that this can be done without compromising efficacy and if permitted by the importing countries.

A new ISPM is being drafted for the international movement of wood. This will include two categories of treatments, firstly those already in use in bilateral trades and with efficacies against specific pests. The second category will be for classes of wood (round wood, sawn wood and mechanically processed wood) and will be based on the draft criteria for future

ISPM No.15 treatment submissions and use the same decision-tree approach.

Alternatives for Logs – Fumigants

Phosphine. New Zealand has pioneered the use of phosphine for the in-transit fumigation of forest produce destined for China but currently it can only be used for the logs shipped below deck in the holds, approximately two-thirds of a shipment. It is now in routine use as a QPS measure, replacing MB use. One of the major disadvantages of phosphine when compared to methyl bromide is the long exposure time (up to 10 days) required, but this is overcome by applying the phosphine in transit. Considerable efficacy data has been developed in support of this methyl bromide alternative (Frontline Biosecurity 2003, Crop & Food 2004, Hosking and Goss 2005, Zhang 2003, Zhang and van Epenhuijsen 2005). However, efficacy data for the wood wasp, *Sirex noctilio,* a quarantine pest of concern for India, has yet to be obtained to the level required for approval for trade with India.

The current dosage specification is for at least 200 ppm phosphine (v/v, 0.28 g m^{-3}) to be maintained for 10 days. Due to sorption of the gas by the logs (Zhang 2004) top-up of phosphine is required five days into the voyage to prevent the concentration falling below 200ppm. In transit tests have shown an even gas distribution throughout the loaded ship holds. High concentrations of CO_2 also occur within the ship holds during the fumigation period that may assist efficacy of the fumigant. The current dosage specification is based on Australian experience with stored grain pests (insects) and is likely to be significantly higher than required where no insect resistance is involved (Frontline Biosecurity 2005).

Phosphine is typically produced in the reaction of aluminium or magnesium phosphide with water. There are some formulations of phosphine available in cylinders as technical grade, pure compressed gas or diluted with CO_2. The gas is highly toxic to insects (see section 6.2.2) and has remarkable penetration ability (Spiers 2003). Because of the relationship between respiration and efficacy, the egg and pupal stages of insects are generally more tolerant than larval and adult stages. Phosphine is generally ineffective against fungi infesting timber (Zhang, pers. com.).

Phosphine has long been used for the treatment of grain insects (see Section 6.2.2) but repeated treatment of grain silos and poorly conducted fumigations has led to high levels of phosphine resistance in stored grain pests in some countries (Zettler 1997, Collinson 1999). Such resistance is not an issue for one way commodities such as forest produce and extrapolation of data on dosage requirements from grain insects may be misleading for forest produce.

Research in China and Japan has demonstrated that phosphine killed 10 species of forest insects of quarantine concern including cerambycids, scolytids and platypodids. Oogita *et al.* (1997) fumigated the cerambycids (*Semanotus japonica, S. japonicus*, *Callidiellum rufipenne*, *Monochamus alternatus*, the scolytids (*Phloeosinus perlatus, Cryphalus fulvus* and *Xyleborus pfeili*) and the platypodids (*Platypus quercivorus* and *P. calamus*)) with phosphine at concentrations of 1.0 and 2.0 g m^{-3} for 24 and 48 hours at 15°C and 25°C. *S. japonica* and *P. perlatus* eggs were killed at 2.0 g m^{-3} for 24 hours at 15°C, but larvae and pupae of all species were not killed at 2.0 g m^{-3} for 48 hours at 15°C. At 2.0 g m^{-3} for 48 hours at 25°C, all stages of *C. fulvus* and *X. pfeili*, except larvae of *C. fulvus*, were killed. The work concluded that more than 48hrs of treatment time was required.

In New Zealand, two phosphine log fumigation trials were completed in 2009 (Wang W. *et al.,* unpublished), using sea containers loaded with commercial export logs and field collected insect-infested logs. The initial dosage of aluminium phosphide in the treatment container was equivalent to 2 g m^{-3} phosphine gas. Phosphine concentration was maintained at over 200 ppm during the 10-day fumigation period with one to three additional applications of aluminium phosphide pellets.

Penetration of the phosphine into export logs at an average moisture content of 59% and 79% respectively to a depth of 80mm achieved an average exposure of 183 ppm.hr and 265 ppm.hr in the two trials.

A total of 680 insects extracted from infested logs in the treatment chambers were dead after phosphine fumigation and the mortality rate was 100%. All 561 insects extracted from the controls were alive. Insects included Cerambycidae; *Arhopalus ferus* (Mulsant) larvae, *Prionopolus reticularis* (White) larvae, Ichneumonidae; Rhyssines larvae (*Sirex noctilio* parasite) and Scolytidae; *Pachycotes pergrinus* (Chapuis) adults, *Hylastes ater* (Paykull) adults, *Hylastes* eggs, *Hylurgus ligniperda* (Fabricus) larvae, *Hylurgus* adults, and *Hexatricha pulverulenta* (Westwood) larvae.

This confirms the laboratory trials carried out by Zhang (2004b) that included four replicates of 94-102 eggs of *A. ferus* were successfully killed at 200ppm for 10 days. In another later trial, a further four replicates of 100-253 *A. ferus eggs* were killed at a mean ppm of 260 over seven days.

Fumigation of logs using *phosphine* is effective in controlling bark beetles, wood-wasps, longhorn beetles and platypodids at a dosage of 1.2 g m^{-3} for 72h at 15 ºC or more. The length of time required to complete treatments restricts its commercial acceptability.
The "Florani" experiment showed that phosphine could be successfully used as an in-transit fumigant for eliminating the pinewood nematode from pine chips (Leesch *et al*. 1989; Dwinell 2001b).

Sulfuryl Fluoride

While sulfuryl fluoride has similar properties and exposure requirements at some temperatures to methyl bromide, with significantly better in penetration of wood (Scheffrahn and Thoms 1993), it is not as effective at lower temperatures and requires significantly higher dosages. Most treatments of logs occur in temperate climates that have temperatures of less than 25°C for much of the year which would make the treatment uneconomic in comparison with methyl bromide treatment. The recommended minimum temperature is 15°C. Sulfuryl fluoride has a large global warming potential (Papadimitriou *at al*. 2008).

Sulfuryl fluoride has long been used for termite control in the USA where it is marketed under the trade name Vikane. The fumigant has been shown to be effective against adult bark and timber insects. However, its efficacy against eggs drops sharply below 21°C requiring increased application rates (USDA 1991a). Dwinnel (2001) recommends a treatment schedule for 24 h sulfuryl fluoride fumigation of unseasoned pine for control of pinewood nematode (*Bursaphelenchus xylophilus*) of 3000 g h m^{-3} at 15°C down to 1000 g h m^{-3} at 35°C or greater.

It does not appear effective against the pinewood nematode (Soma *et al.* 2001) either at 40 g m^{-3} for 24hrs or 20 g m^{-3} for 48hrs at 15°C. Its performance against the wide range of fungi of quarantine significance is unclear, though sulfuryl fluoride has successfully killed oak wilt fungus in 72 hrs at rates similar to methyl bromide (Carpenter *et al.* 2000; Tubajika 2006). Also at 30 g m^{-3} all eight wood fungi tested failed to grow after re-isolation (Zhang and van Epenhuijsen 2005).

Methyl Isothocyanate/Sulfuryl Fluoride Mixture

The mixed gas of MITC and SF was registered in Japan in 2004 for logs infested with forest insect pests. MITC does have high sorption characteristics and an odour (UNEP 2001). MITC used in mixture with CO2 is effective against wood borers, bark beetles, and ambrosia beetles at 40-60 g m^{-3} for 24hrs at 15^{o}C (Naito *et al.*, 1998). It has been found to be particularly effective against pinewood nematode (Soma *et al.*, 2001).

Soma *et al.* (2004), using the fumigant mixture of SF and MITC (sulfuryl fluoride 30%, MITC 30% and carbon dioxide 40%, w/w), demonstrated that all stages of three kinds of forest insect species, alnus ambrosia beetle (*Xyleborus germanus*), ambrosia beetle (*Xyleborus pfeili*) and pine bark beetle (*Cryphalus fulvus*) and adult stage of smaller Japanese cedar longicorn (*Callidiellum rufipenne*) were killed 100% at the dosages of SF15 g m^{-3} + MITC 15 g m^{-3} and of SF 21 g m^{-3} + MITC 21 g m^{-3} at temperature range of 18.3-21.2°C. However, achieving a complete kill for each of species tested was difficult when the insects had been fumigated with single gas of SF or MITC. These four species were considered less tolerant to mixture fumigant than pinewood nematode (*B. xylophilius*) and a large scale mortality test using pine wood nematode provided complete kill of 97,400, 59,500 and 22,700 individuals with SF 27 g m^{-3} + MITC 27 g m^{-3} at 10°C, SF 21 g m^{-3} + MITC 21 g m^{-3} at 15°C, and SF 15 g m^{-3} + MITC 15 g m^{-3} at 25°C, respectively (Soma *et al.*, 2006).

The sulfuryl fluoride/methyl isothiocyanate mixture was recently registered as an agrochemical in Japan.

Methyl Iodide

In Japan, the development of alternative chemicals to methyl bromide for imported logs has been carried out by a research institute on plant protection of the Ministry of Agriculture, Forestry and Fisheries (MAFF 2009), manufacturers and other bodies concerned with MB use as

Complete mortality of the pinewood nematode and the longhorn beetles, *Monochamus alternatus* and *Arhopalus rusticus*, were attained at 84 g m^{-3} at 10 ^{o}C, 60 g m^{-3} at 15 ^{o}C, 64 g m^{-3} at 20 ^{o}C, 48 g m^{-3} at 25 ^{o}C respectively using methyl iodide 50% and carbon dioxide 50% (Kawakami *et. al* 2004). This mixture is now registered in Japan for timber treatment. The limited amount of research that has been undertaken suggests it is no better than methyl bromide in controlling pathogens in wood and may in fact be inferior (Schmidt and Amburgey 1997).

Nine kinds of insect pest species for logs, smaller Japanese cedar longicorn (*Callidiellum rufipenne*), Japanese pine sawyer (*Monochamus alternatus*), cryptomeria bark borer (*Semanotus japonicus*), pine bark beetle (*Cryphalus fulvus*), Iarch ips (*Ips cembrae*), ambrosia beetle (*Xyleborus pfeili)*, alnus ambrosia beetle (*Xylosandrus germanus*), yellow-spotted pine weevil (*Pissodes nitidus*), and pine weevil (*Shirahoshizo rufescens*) were fumigated with methyl iodide and the egg stages were found to be more susceptible. Also, larval and pupal stages showed similar susceptibilities. All tested species except for smaller Japanese cedar longicorn (*C. rufipenne*) were killed completely with the fumigation of methyl iodide at 50 g m^{-3} for 24 hours at 15^{o}C (Naito *et al*., 2003).

Mortality tests for pine wood nematode (*Bursaphelenchus xylophilus*), which indicated almost equal tolerance to methyl iodide with above mentioned nine species, provided more than 99% mortality for nematodes that were fumigated with methyl iodide at 30 g m^{-3} at 15°C and 100% mortality was obtained with 40 g m^{-3} of dosage (Soma *et al*., 2005). Subsequently, a large scale mortality test for pine wood nematode was examined at three different temperatures and 10,800, 33,500 and 22,400 individuals were killed completely at 10°C with 60 g m^{-3}, 15°C with 40-50 g m^{-3} and 25°C with 30 g m^{-3}, respectively (Soma *et al*., 2005). Thus, 87,800 nematodes in total were completely killed by lower dosages than the nominated standards of plant quarantine. It is expected to be adopted as a quarantine treatment in the near future.

Methyl iodide has successfully killed oak wilt fungus at rates similar to methyl bromide (Tubajika, 2006). This material was recently registered as an agrochemical in Japan.

Cyanogen

Cyanogen, sometimes referred to as ethanedinitrile, has been investigated as a replacement for methyl bromide. Registration is currently being sought in Australia. Ren *et al*. (2006) found direct exposure of Asian longhorned beetle larvae at 21 °C required a *ct*-product of 56.6 g h m^{-3} over 6 hours to give 99.5% mortality, equivalent to an exposure of 9.4 g m^{-3} over 6 hours. At a low temperature of 4.4 °C, an exposure to 94 g m^{-3} over 3 hours was required for 99.5% mortality. Trials reported by Dowsett *et al*. (2004) showed cyanogen to be more effective than methyl bromide on a *ct*-product basis against all life stages of two species of timber beetles and one species of termite. At 50 g m^{-3} and at 4.1°C for 1 day cyanogen caused >96.5% mortality of the pinewood nematode *Bursapelenchus xylophilus* and the nematode *Steinernema carpocapsae*, a beneficial, was killed at 40 g m^{-3} and 20°C after a 5 hour exposure.

Full scale trials using cyanogen on stacks of sawn timber have been carried out in Malaysia under MLF-funded demonstration trials for methyl bromide alternatives (UNDP - MAL/99/G68/A/2G/99). Cyanogen penetrates wood quite rapidly both across and along the grain, in contrast to methyl bromide that travels along the grain but poorly across the grain (Ren *et al*. 1997). Unlike methyl bromide, it appears to penetrate high moisture content timber well. More data is needed on this. It appears to have considerable potential as a methyl bromide alternative for logs (Wright *et al*. 2002).

Alternatives – Non-fumigants

Heat treatment has been accepted as a quarantine treatment for logs and timber to be shipped to the USA and many other countries for many years (e.g. USDA 1996). The general specification has been to reach a core temperature of 71°C for 60 minutes. Kiln drying of timber to a moisture content of less than 20% using temperatures over 70°C is often a commercial requirement but also has long been accepted as a quarantine treatment by most importing countries. Currently 56°C for 30 minutes core temperature is sufficient for wood packaging.

Heat treatment of unprocessed logs is an approved risk mitigation measure for import into the USA (Morrell 1995) but because of the energy required and the bulk of the commodity, it is rarely an economic alternative to fumigation. Steam heat is a more effective quarantine measure than dry heat (USDA 1994, Dwinell 2001).

Hot water and steam treatment has long been used for risk mitigation for hardwood veneer logs imported into New Zealand. Such logs are invariably attacked by pinhole borers (*Scolytidae* and *Platypodidae*) before shipment. Moist heat treatment is an integral part of log conditioning prior to peeling but has the additional benefit of eliminating quarantine risk.

A considerable volume of literature addresses thermal mortality of insects and has been reviewed by Hosking (2002a). Jamieson et al (2003) provides a good general summary of the literature on heat mortality of insects and fungi. A summary of heat treatment applications for forestry produce is that of Dwinell (2001).

This literature suggests few if any insects and their close relatives can survive even short exposure (less than 24h) to temperatures above 50°C, but some fungi are more tolerant. Direct exposure trials of gypsy moth eggs (Hosking 2001) found 100% mortality for the lowest temperature (55°C) and shortest exposure time (5minutes) tested. Fungi have been shown to be more variable in temperature mortality threshold and the required exposure time, some requiring exposures up to 6 hours at 57°C (Morrell 1995) while others are killed at 60°C for 10 minutes (Ridley and Crabtree 2001). Heat treatment by steam has been shown to eradicate all tested fungi when 66°C is held at the centre of wood for 1.25 hour (Miric and Willeitner 1990, Newbill and Morrell 1991), but Dwinell (2002) reported that neither the APHIS-approved MB treatment for timber nor heat treatment up to 81°C killed all saprophytic fungal pathogens in imported hardwood pallets. Many fungal pathogens are also very tolerant of methyl bromide (e.g. see Rhatigan *et al*. 1998)

Irradiation
Gamma irradiation has been suggested as a treatment for wood and wood products (Reichmuth, 2002), and is currently approved for logs imported into Australia at a rate of 10 kGray (1.0 Mrad). However, its practical application must overcome a number of hurdles, not the least being the construction of large irradiators to handle logs and bulk wood products. The technology is also limited by poor penetration into freshly cut logs, potential damage and degradation of wood products such as fibre board and paper, variation in effect on different insect groups, and very high dosages required to eliminate fungi (Morrell 1995).

Irradiation to eradicate the pine wood nematode (*Bursaphelenchus xylophilus*) in pine chips has been investigated. Pine wood nematode-infested wood chips were exposed (for periods from 1 h to 2 weeks) to gamma ray doses up to 12 kGy. Lethal doses lay in the range above 6 to 9 kGy, which was considered too high to make irradiation an economically attractive means of decontaminating commercial wood chips. Forintek Canada Corp. researchers reported that a similar dosage of 7 kGy was required to kill pine wood nematodes in aqueous solution, which supports the contention that a higher dosage is necessary to eliminate the pine wood nematode in vivo than in vitro. Recent studies on irradiation effects on other nematodes confirmed the relatively high dosages required to cause mortality (i.e. a dose of 7.5 kGy was required to kill all J2 larvae of *Meloidogyne javanica*). The use of irradiation for decontaminating logs in export trade does not appear to be economically feasible at this time, but may be useful in managing pests on high-value forest products that cannot normally be heat-treated or fumigated.

Water soaking or immersion provides a process for control of pests on imported logs. Immersion of some logs destined for plywood manufacture is a useful process as it improves the quality of the products. The storage of logs in water or under water spray has long been accepted as an effective treatment for terrestrial insects and fungi. Salt water immersion for

30 days is an approved treatment for logs imported into Japan but contamination of waterways with bark is an issue. The upper surface of the logs above the water level is sprayed with an insecticide mixture such as dichlorvos as part of the pest management strategy (Reichmuth 2002).

The potential for use of water soaking for quarantine treatment of imported logs is limited by the large area of water required and the undesirable side effects of ponding large volumes of logs, making its application on a large scale unlikely.

Debarking

Bark removal has long been a key strategy in reducing contamination of logs and reducing the risk that logs and sawn timber carry insects and fungi of quarantine concern. While debarking removes surface contamination and also bark and cambium, areas particularly prone to pest attack; it does not affect insects and fungi already in the wood (USDA, 1992).

Many countries require debarking of all imported logs. Because of the high cost, and the requirement by customers in major Asian markets that bark remain on logs, its application as a quarantine treatment is limited and frequently only carried out on high value logs.

Microwave Treatment

This is essentially a heat treatment using electromagnetic energy in the 10 – 30,000 MHz range. The relationship between field intensity, exposure time and mortality of individual insect species is not well understood, but has been shown to include considerable variability (Ria *et al.* 1972, Ikediala *et al.* 1999).

Forest produce poses special problems in the use of microwaves for disinfestation both in the wide variation in moisture content and the variety of target insects. However, recent research by Fleming *et al.* (2003) has shown microwave irradiation to be highly effective against Asian longhorned beetle in both green and dry wood packaging up to 100 x 100 x 100 mm.

Microwave irradiation has also been shown to be effective against termites (Lewis *et al*. 2000). It seems unlikely, however, that microwave irradiation has application in the treatment of logs in the quantities exported, and even scaling up the technology to deal with quarantine risk wood packaging poses some serious challenges.

Trends in the Log Trade

It is recognized that unmanufactured wood, especially in raw log form, is a particularly high-risk pathway for movement of forest insects and pathogens into new environments and treatment is usually required either preshipment or on arrival. The main approved treatment is methyl bromide with a small volume in trade using phosphine. The increasing world trade in logs and unmanufactured wood articles to fast growing economies such as China and India has amplified the consumption of methyl bromide in this sector.

From 1999 to 2007 the imports of logs into China grew by 230%. While the bulk of the logs going into China are from Russia via the land border and do not require treatment, a significant proportion is shipped by sea and requires treatment, as do those logs shipped from other countries. India has experienced a 92% increase over the same period and is likely to continue to grow. These increases have been offset slightly by a decrease in the log trade to both Japan (down 46%) and S. Korea (down 14%) over the same period. The net effect has been a 56%

increase in imports over the eight year period, with increased need for quarantine treatment of some kind.

Fig 2-6: Trends in log trade in Asia 1999 – 2007

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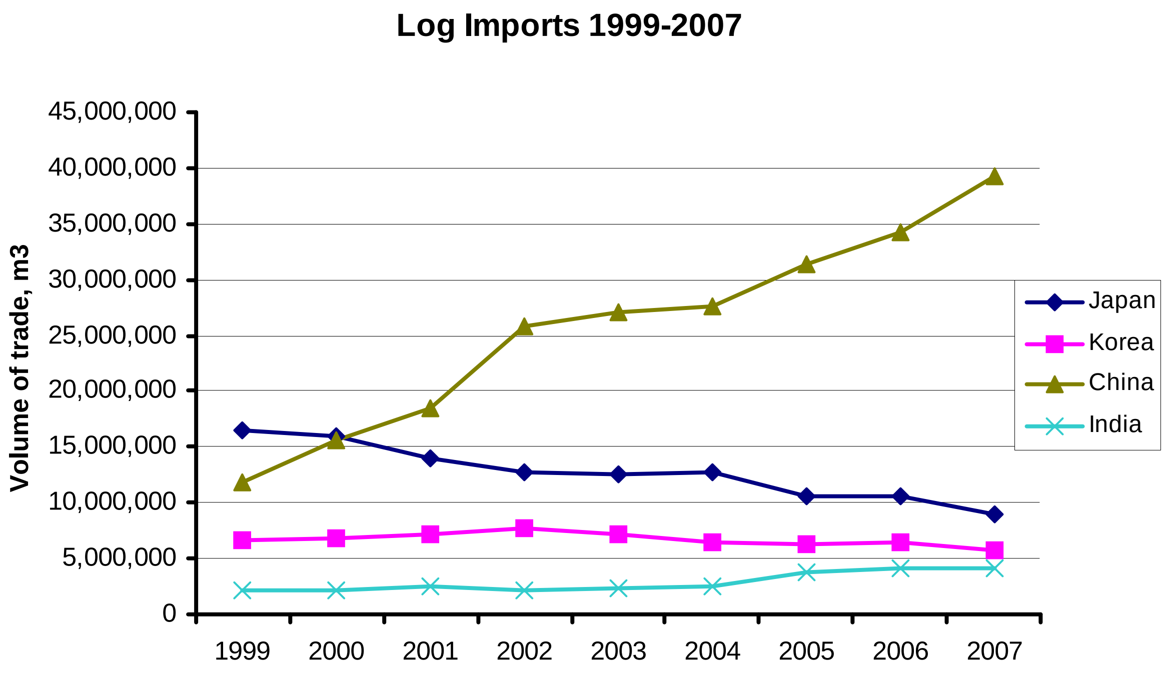

Heat Treatment of Wood Packaging Materials

The only alternative treatment to methyl bromide treatment accepted internationally under ISPM 15 for treatment of wood packaging materials (WPM) is heat treatment, including kiln drying. A temperature of at least 56°C, core temperature, must be maintained for at least 30 minutes (IPPC, 2006). The 2009 version of the ISPM 15 standard (IPPC 2009) specifically encourages use of heat where feasible in preference to methyl bromide. There is substantial use of the heat treatment in many countries to meet ISPM 15. In general, heat treatment requires a higher level of infrastructure compared with methyl bromide fumigation.

There are some trends to comply with the ISPM 15 standard entirely with heat treatments and without using methyl bromide. The EC has published a manual of options and alternatives to achieve the objectives of ISPM 15 without using MB (Vermeulen and Kool, 2006). Also, in this manual, two possible alternatives to MB, controlled atmosphere and sulfuryl fluoride, are discussed.

A variety of facilities are in use to achieve the specified heat dosage for ISPM 15. They include timber kilns (present in many countries), hot water dipping (e.g. Bangladesh (Kabir, 2005)), and modified freight containers or similar enclosures with either hot water heating (China) or electrical or gas heating (Australia, Jamaica). Heat has been used in many A5 countries for many years (e.g. Morocco, Costa Rica, Colombia, Ecuador) and is made easier due to the fact that it can be integrated with kiln drying. CFIA (2007) describes procedures for measuring and achieving ISPM15 heat conditions with both green and dried wood. The AQIS standard for heat treatment (AQIS 2009) gives procedures for measuring heat dosages to meet ISPM 15 and for treatment of other commodities.

Chemical Alternatives in WPM

In cases where WPM has to be treated together with heat-vulnerable cargoes or goods to meet ISPM 15, there is no chemical option at present other than MB treatment[2], but alternative chemicals are being evaluated. The 2009 revision of ISPM 15 (IPPC 2009) did not recognise any alternative to methyl bromide except heat, but several potential alternatives to heat and methyl bromide are under continued testing. The Technical Panel on Phytosanitary Measures (TPPT), the panel that advises the CPM on technical evaluations on alternatives, reports that several potential alternatives have been submitted to the IPPC and are under evaluation.

The alternatives listed in Table 2-7 were submitted to IPPC and have been evaluated in accordance with the IPPC process. The evaluation panels have requested additional efficacy data for all the potential alternatives. It seems that species of *Agrilus planipennis* (Emerald Ash Borer), *Anoplophora glabripennis* (Asian longhorned beetle, ALB) and *Bursaphelenchus xylophilus* (Pinewood nematode, PWN) are key pests that at least need to be controlled to a very high level of quarantine security by any alternative.

[2] ISPM 15 requires the wood packing material to be treated to the required standard before it is stamped. However, on some occasions, it appears that stamping occurs prior to treatment. This gives potential to expose heat sensitive articles to the treatment.

Table 2-7: List of potential treatments for ISPM-15 under IPPC evaluation

Sulfuryl fluoride
Sulfuryl fluoride and MITC mixture
Hydrogen cyanide
Microwave irradiation
Phosphine
Methyl iodide

Of the alternatives for ISPM 15 being considered, the data submitted for sulfuryl fluoride are sufficient to support Probit-9 efficacy for SF fumigation against *Anoplophora glabripennis* in wood packaging material, but not for pinewood nematode. The TPPT has sufficient information to support the 99.99683% (Probit-9) efficacy of a methyl iodide schedule against PWN with but not for *Anoplophora*. Phosphine data submitted are not yet sufficient to demonstrate efficacy against either of the two key pests.

A new ISPM is being drafted for the international movement of wood that will include two categories of treatments, firstly those already in use in bilateral trades and with efficacies against specific pests. The second category will be for classes of wood (round wood, sawn wood and mechanically processed wood) and will be based on the draft criteria for future ISPM No.15 treatment submissions and use the same decision-tree approach.

Not in-kind Alternatives for WPM

Not-in-kind alternatives exist for wood pallets and other wooden packaging materials. These avoid the need for MB fumigation or heat treatment. Plastic pallets (often made from recycled plastic and reusable) are commercially available and are used by many companies in the EC, the US[3] and many other regions of the world. Cardboard pallets can be suitable for loads of about 3,000 kg, for example, and are available commercially in Australia, the EC, Kenya, New Zealand, the US and others[4]. Plastic, cardboard, plywood and particle board can also be used, instead of wood packing materials, for boxes, containers and staves which prevent goods moving within packed shipping containers. These materials are exempt from the requirements for MB or heat treatments under the ISPM 15 standard, which refers only to solid wood packaging materials. The ISPM 15 standard excludes non-wood packaging (plastic, cardboard) and specifically excludes plywood, particle board, oriented strand board and similar processed wood that has been subjected to glue or pressure during processing (IPPC 2009, Appendix 4, section 2.1). As a side benefit, a reduction in the volume of new timber used for wood pallets would bring benefits to countries where forest resources are under pressure. Kenya, for example, is estimated to use about 250,000 to 300,000 wood pallets per annum for tea exports alone. This

[3] Examples of plastic pallets can be found at www.USplasticpallets.com, www.cabka.com, www.plasticpallet.eu, www.goplasticpallets.com, www.rwrpaletten.be, www.craemer.de, www.permapallets.nl, www.palletower.com, www.plastibac.eu.

[4] Examples of cardboard pallets can be found at www.cardboardpalletcompany.com.au, www.tripla.com, http://www.jmpholdings.com.au/palletscorrugated.html, www.farusa.dk, www.doubleEco.co.nz.

volume of pallets comprises about 5,500-6,600 tonnes of cut timber, which requires the felling or importation of about 8,330 - 10,000 tonnes of raw timber per annum (Rodwell, 2007). This demand for timber causes problems in Kenya where the tree cover is rapidly dwindling due to other pressures such as the need for firewood (Rodwell, 2007).

Alternatives Under Development for WPM

The requirement for mortality data showing a high level of effectiveness for wide range of pests is a major barrier to development and approval of additional alternative treatments for ISPM 15. Details of current requirements for submission of potential alternatives are given in ISPM 28. Criteria for future ISPM 15 treatment submissions are being considered by the TPPT.

Some NPPOs recognise other treatments for wood packaging materials and similar products where ISPM is not applied. These treatments may be post entry or prior to export. Australia, for instance, accepts off-shore treatments of timber packaging and dunnage not treated in accordance with ISPM 15 must at specified dosages of several alternatives, including fumigation with sulfuryl fluoride, or ethylene oxide or treatment with heat, gamma irradiation or some timber preservatives (ICON 2009)

Evaluation and use of alternatives was reported by the EC in 2007 as follows (Touchdown, 2009):

- Heat treatments were used in their territories for the disinfestation of pallets and packaging materials (Bulgaria, France, Germany, Greece, Hungary, Ireland, the Netherlands, Poland, Slovenia, Spain). Heat treatment facilities were registered in Portugal and the UK;
- Research was underway on sulfuryl fluoride (SF) to control a range of pests infesting wood (France, Germany, Greece, Ireland, Portugal and Spain). The Netherlands registered SF in 2007 and Greece in 2009.
- Hungary researched hydrogen cyanide (HCN) for the control of wood boring insects. There was collaboration between Hungary and a company in the Czech Republic that was the owner of the HCN formulation. There was interest in obtaining IPPC accreditation for the use of HCN, perhaps as one of the alternatives listed under ISPM 15.

Uses Where No Alternatives Have Been Identified

Given existing gaps of information, lack of research on effectiveness of some alternatives and regulatory constraints affecting their implementation in some situations, it is presently difficult to clearly identify QPS uses of methyl bromide where no alternatives exist. In some cases, although alternatives exist, they may not be available for a particular situation or country. Nevertheless, in the light of information available, the QPSTF was able to identify some areas where implemetation of alternatives seems particularly complicated or difficult. For perishable commodities, the QPSTF noted there were currently no approved alternatives for certain economically important exports (the list is not all inclusive):

- Apple, pear and stonefruit that are hosts to codling moth, for example
- Nectarines from USA, codling moth
- Nectarine from New Zealand, codling moth
- Apples from New Zealand, codling moth
- Apples from France, MED fly and codling moth

- Apples from Australia (Tasmania), codling moth
- Cherries from Chile, codling moth
- For certain pests on berryfruit
- For grapes infested with, for example mites, exported to some countries (although Chile has developed a systems approach allowing export to the USA)
- Some root crops exported by countries if soil was present or pests of concern were detected on arrival
- Post entry quarantine treatment of cut flowers and some other perishables as an alternative to destruction or rejection of the cargo.

Similarly, there are certain current QPS uses of methyl bromide on durables for which QPSTF did not identify any existing alternatives. These were disinfestation of (not an exhaustive list):

- Seed-borne nematodes from alfalfa and some other seeds for planting.
- Treatments against khapra beetle or risk thereof in grain and packaged goods at risk of carrying the pest. Moderate heat is not approved. Phosphine treatment is also not approved, and possibly unwise in view of phosphine resistance with this pest.
- Treatments against snails, particularly white snails such as *Theba pisana* in grain. MB does not work well but is only available treatment.
- Treatment of whole logs at risk of carrying both insect quarantine (regulated) pests and *Bursaphelencus* nematodes.
- Treatment of oak logs and oak products at risk of carrying oak wilt fungus.
- Treatment of wood packaging material to ISPM 15 requirements, where heat treatment is not feasible (however, as decsribed above there are not in kind options available).
- Treatment of large bulks of soil as a commodity, where steaming cannot be used for disinfestation against quarantine fungi and weed seeds.

For preplant soil uses of methyl bromide classified as QPS, there are alternatives that are effective for almost all instances, but lack of regulation of a key alternative, methyl iodide and future concerns over regulation of a number of other fumigant alternatives may limit future options.

In areas where methyl iodide is not registered, MB is the key fumigant required to eradicate quarantine and regulated non-quarantine pests and pathogens such as potato cyst nematode and golden nematode.

Feasible alternative options are a)inspection programmes prior to shipment, b) total prohibition of a particular trade, or c) processing products prior to export (e.g. exporting cut dried timber rather than raw, whole logs) in order to avoid excessive risk of carrying quarantine pests. For some commodities, methyl bromide fumigation may be the only approved treatment at present to allow the trade (e.g. export of apples to Japan from Tasmania).

Summary: Alternatives to Methyl Bromide

All of the categories appearing in the sections above have approved non-methyl bromide alternatives in at least some applications. Specific alternatives may not be available for a particular trade or situation because of the risk or presence of particular quarantine pests, lack of approval by the importing NPPO, or lack of registration or commercial supply of the particular treatment.

Section III. Opportunities for Emission Reduction and Recovery

In the absence of effective containment and recapture or reuse technologies, most methyl bromide applied to a QPS fumigation is subsequently released or lost by leakage to the atmosphere. The fraction of applied methyl bromide that is lost from a specific fumigation depends on the quantity of the applied methyl bromide that reacts with various components in the commodity and associated materials and structures. This reaction leads to non-volatile bromine ion residues. Estimates of the fraction emitted from particular categories of fumigation, including for QPS purposes, can be found in MBTOC (2006) and previous Assessments.

There are a variety of measures that can be taken to reduce the relative or absolute fraction of the applied methyl bromide emitted in a particular QPS application. These are discussed below. The various emission reduction techniques can affect the proportion of initially applied methyl bromide that is subsequently available for recapture and potentially, reuse.

At this time, recapture technologies are commercially available for QPS and other treatments using methyl bromide on commodities and structures, but not for soil treatment in situ. There are a variety of emission mitigation measures that can be applied to QPS and other methyl bromide fumigations for soils in situ.

Quantities of QPS Methyl Bromide Emissions Available for Recapture and Destruction
The total quantity of methyl bromide emitted from a fumigation, during dosing, by leakage during the exposure, by venting at the end of the exposure and by subsequent airing off of sorbed methyl bromide, provides an upper limit to the quantity of methyl bromide available for recapture. The remaining fraction of the initial applied gas is converted to non-volatile bromide ion residues.

Different commodities vary widely in their ability to sorb methyl bromide and to react with methyl bromide. In the QPS commodity treatment sector, fresh fruit and vegetables treated in gastight fumigation chambers at short exposure times absorb little methyl bromide and over 95% of the applied dosage may be available for recapture. High protein, milled commodities such as oilseed expeller cake may absorb more than 80% of applied dosage over a 24 hour exposure, leaving less that 20% of dosage available for recapture. Temperature and load factor also influence methyl bromide available for recapture in the absence of significant leakage.

Some treatment schedules for QPS treatments of commodities specify a minimum retention of concentration of methyl bromide at the end of the exposure period. While this is usually specified to ensure an adequate exposure (*ct*-product) is achieved for effectiveness against the target QPS pests, this does give an indication of the likely potential emissions from the processes at the end of the treatment, in the absence of any recapture or destruction process.

Table 3-1 gives examples of minimum retention of methyl bromide specified by some QPS-related standards. These schedules approximately define the minimum quantity of methyl bromide readily available for recapture or destruction under the schedule.

There is some uncertainty as to the actual residual quantity present after fumigation, as the measurements relate only to concentration. In normal fumigation practice, it is usually assumed that the methyl bromide is present at the measured concentration throughout the fumigation enclosure and the product of enclosure volume and concentration indicates the quantity present. However this does not take into account either the exclusion volume of the fumigated materials nor the quantity of gas that may be sorbed, unchanged, on these materials.

Table 3-1. Examples of standard QPS methyl bromide treatment schedules that specify end point concentrations.

Treatment schedule or standard	**Exposure period**	**Minimum % of initial specified dosage rate**
AQIS (2008a) Methyl Bromide Fumigation Standard	2 h	60%
ISPM 15 (2009) for Solid Wood Packing Material	24 h	50%
MAFF (1951) standard for imported logs	24h	31%
AQIS (2008a) Methyl Bromide Fumigation Standard	24 h	30%
T404-d treatment (70-79F) against wood borers and khapra beetle (USDA 2009)	24h	30%
MAFF (1951) standard for imported logs	48h	25%
MAFF (1951) standard for imported logs	72h	21%

Estimates of total methyl bromide emitted from fumigations under standard industrial practice differ from those based on residual concentration data. Total emissions include losses during initial application and leakage during the exposure, in addition to quantities vented from the fumigation at the end of the exposure and subsequent airing off of residual sorbed gas.

Table 3-2 gives calculations of total emissions from various categories of QPS treatment, including soils treatments, for the year 2007. Annual methyl bromide emissions are likely to have been similar in magnitude over the previous 5 years, since annual consumption has remained approximately constant over these years. The overall actual annual emission rate is dependent on the rate of accumulation or use of any stocks in each year.

Table 3-2. Estimates of emissions from various commodities fumigated with methyl bromide

Fumigated material or situation	MB used (2007, tonnes)[b]	Estimated % MB emitted, with standard industrial practice[c]	Estimated MB emitted (tonnes)
Grains, nuts and dried fruit	1618	51 – 70	825 – 1132
Timber and wood packaging	3865	88	3401
Fresh fruit and vegetables and other perishables	821	85 – 95	698-780
Other commodities and unidentified use	651	80 – 95	521-618
Soils, in situ	1531	40 – 92	612-1409
Totals and weighted[a] estimates	8486	71 – 86	6057-7341
Discrepancy (total reported consumption, less use, Table 4-6)	1824	71 – 86	

a estimates weighted by tonnage
b data from Table 4-6, this report
c based on estimates from Table 9.1 of MBTOC (1998)

Table 3-2 shows that emissions from QPS treatments are likely to be in the range of 71 – 86%, with a mean estimate of 79%, of applied methyl bromide in absence of recapture and destruction processes and with standard industrial practice. Assuming that recapture from soil fumigation is not technically and commercially feasible at this time, the estimated total methyl bromide available for recapture in 2007 from QPS commodity fumigations is 5,445 – 5,932 tonnes, being about 67% of estimated 2007 annual QPS use of 8,486 tonnes and a mean of 82% of QPS methyl bromide applied to commodities.

Emission Reduction Processes and Technologies
Reducing Volumes of Methyl Bromide Use as a Phytosanitary Measure

The IPPC recommendation 'Replacement or reduction of the use of methyl bromide as a phytosanitary measure' (IPPC 2008) states that the reduction of methyl bromide emissions can be achieved through the use of reduced dosages of methyl bromide as a phytosanitary measure or decreased treatment frequency. In addition, existing methyl bromide use should be analysed carefully to determine if the treatment is appropriate and necessary.

The following approaches may, where appropriate, be pursued to reduce the use of methyl bromide as a phytosanitary measure (IPPC 2008):

- inspection-based fumigation instead of mandatory fumigation (i.e. to detect and identify the quarantine pest of concern)
- avoidance of unjustified re-fumigation with methyl bromide (i.e. re-fumigation should be used only when a quarantine pest situation is evident)
- improvement of treatment facilities as appropriate to maximize efficiency of fumigation, thus reducing replenishment or re-fumigation requirements
- increasing exposure time with a view to reducing dosage, where technically feasible
- compliance with phytosanitary requirements for exporting commodities
- avoidance of application in situations where efficacy is doubtful or marginal
- reassessment of doses and exposure times in order to reduce them
- use of optimal temperatures when fumigating
- use of appropriately sized treatment facilities
- evaluation of pest risk and treatment efficacy (through a pest risk analysis) to determine if a more appropriate dose or alternative treatment is possible.

Application of Best Practices

Several quarantine authorities (NPPOs) have codes of practice or similar documents that detail best practice in use of methyl bromide for QPS treatment of commodities. These include sections in the USDA PPQ manual (USDA 2009, USA), AQIS Methyl Bromide Fumigation Standard (AQIS 2009a, Australia) and Theory and Practice of Plant Quarantine Treatments (JFTA 2002, Japan). The FAO web-based document 'Guide to Fumigation under Gas-Proof Sheets' (FAO 2009) also provides instruction on use of methyl bromide for QPS treatments. Use of best practices for QPS treatment of commodities minimises emission losses (leakage) prior to venting at the end of treatment, while maximising effectiveness of a particular dosage of methyl bromide.

Treatment of commodities for QPS purposes under best practice is typically carried out in well sealed enclosures designed to retain the fumigant gas at effective levels throughout the exposure time of the treatment. The level of sealing should be such as to minimise unintentional fumigant loss, caused by atmospheric forces such as wind and temperature changes (e.g. van Someren Graver and Banks, 2008). There are a range of standards set for sealing of enclosures (freight containers, fumigation chambers, sheeted stacks, silo bins, sheds etc.) for fumigation with methyl bromide. These standards vary with circumstances and country regulations or codes of practice. They are typically based either on a pressure test or a gas retention test, with a pressure half life of 10 seconds to 5 minutes and gas retentions exceeding 70% of initial dosage at the end of a 24h exposure in an empty fumigation enclosure, with circulation fans running, if applicable.

A fumigation enclosure used with methyl bromide must be well sealed in order to minimise gas loss for both industrial safety and efficacy reasons. In practice, methyl bromide treatments of commodities, for both QPS and other purposes, are often carried out in poorly sealed enclosures with substantial rates of gas loss. To compensate for this loss, some NPPOs and other authorities (e.g. AQIS 2009, USDA 2009) allow 'top up', a process of adding additional methyl bromide during the course of a fumigation to maintain effective gas concentrations. This top up process may give a good treatment from QPS point of view, but leads to increased methyl bromide use and emissions compared with adoption of better sealing. This is under conditions where gas loss occurs from leakage, not reaction and sorption on the commodity and packaging.

Application of audited best practice for QPS fumigations in several countries that trade with Australia under the AFAS scheme has saved (avoided use of) substantial quantities of methyl bromide. It is estimated that AFAS countries (India, Indonesia, Malaysia and Thailand) have collectively reduced methyl bromide usage by 153 tonnes from 2004 to 2008 (Fox 2008, Cox 2008) This saving was achieved largely through avoiding repeated methyl fumigations after failures in the initial treatments were detected.

Gas Transfer Systems

Some savings in methyl bromide usage can be obtained from transferring the residual methyl bromide gas in a fumigation to another undosed fumigation enclosure loaded with material to be treated.

As an example, two large fumigation systems located at the Taicang port in Jiangsu province and the Putian port in Fujian province have been constructed in China for methyl bromide fumigation of imported timber. They each have an annual treatment capacity of 1.5 million m^3. Automatic control and monitoring systems were incorporated into these two facilities. These include dosage, recirculation, concentration monitoring, and gas transfer between tanks. After each fumigation cycle, half of the gas residue in one tank can be transferred through the recirculation fan and pipe system to any other tank in the system. After one and half years in operation, more than 2.5 million m^3 of imported timber have been treated at these two facilities and MB usage for the purpose has been reduced by more than 60 tonnes of methyl bromide.

Prolonged Exposures

In theory, extending the exposure period or contact time that methyl bromide has with a reactive fumigated commodity allows more of the added fumigant to decompose to non-volatile residues, thus reducing methyl bromide emissions. Prolonged exposures at a particular dosage may also result in greater ct-products, giving scope for dosage reduction and, consequently, reduced emissions.

Prolonged exposures combined with barrier films are in use with soil fumigations as a means of extending fumigation periods and reducing dosage requirements, and incidentally, emissions. Prolonged exposures, as a means of reducing emissions, tends to be unsuitable in practice for commodity treatments. Many commodities, particularly perishables, are damaged by prolonged exposure to methyl bromide. In port situations, where QPS commodity fumigations are typically carried out, a rapid rate of treatment is required for logistic reasons.

Technologies for MB Recovery, Containment and Recycling from Commodity Treatments

Recapture of Methyl Bromide from QPS Commodity Treatments

Methyl bromide QPS treatments of commodities, carried out under best practice, are well suited to the application of recapture systems for minimising emissions of methyl bromide. Good sealing of the fumigation enclosure is a prerequisite for efficient recapture of methyl bromide as it minimises leakage from the enclosure during the exposure to the gas.

There are many different possible systems with potential to destroy methyl bromide gas vented from fumigations or recapture methyl bromide for reclamation and recycling or for destruction. All these systems should be capable of handling methyl bromide gas concentrations in the range of about 10 – 100 g m^{-3}, typical of gas concentration remaining after a fumigation exposure period is complete, with high recapture or destruction efficiency.

MBTOC (2002, 2007) summarised approaches to methyl bromide recapture and destruction, with details of several commercial installations.

TEAP (2007) summarized responses from Parties to Decision XVII/11 that read in part:

"*To encourage Parties who have deployed in the past, currently deploy or plan to deploy technologies to recapture/recycle/destroy or reduce methyl bromide emissions from fixed facilities or sea container fumigation applications to submit to the Technology and Economic Assessment Panel details of efficacy, including destruction and removal efficiency (DRE), logistical issues and the economic feasibility of such fumigations, by 1 April 2006*".

Commercially available systems for recapture of methyl bromide, known to QPSTF at this time are detailed in Table 3-3, together with destruction efficiencies as obtained under Decision XVII/11.

Table 3-3. Available systems for recapture of MB

Supplier	System	Unit or module capacity	Installations	Disposal of sorbed methyl bromide	URL
Desclean, Belgium	Absorption on activated charcoal, with cooling	Carbon loadings of up to 1: 3 by weight, typically for fumigated freight containers	Transportable system – Belgium	Incineration or thermal desorption and reuse	www.desclean.be
Nordiko, Australia	Absorption on activated charcoal, ambient temperature	Typical carbon loadings of 1:5 by weight. Installations for permanent fumigation chambers, freight containers and fumigations under sheets	Australia, Malaysia, Belgium, China, New Zealand etc	Reaction with sodium thiosulphate solution or landfill	www.nordiko.com.au
TIGG, USA	Absorption on activated charcoal, ambient temperature	Fitted to large fumigation chambers	Houston and Watsonville, USA	Incineration off-site in specialized facility, with recovery of bromine component	www.tigg.com

All operational commercial recovery units known to QPSTF, given in Table 3-3, are based on recapture of methyl bromide on activated carbon. Subsequent treatment of the carbon loaded with methyl bromide varies with supplier and situation. Most systems have chosen to operate with a destruction component for the recaptured methyl bromide, but potentially the methyl bromide absorbed on the carbon can be released for reuse by heating the carbon to typically 130-170°C. The Desclean system operates by initially cooling the carbon absorption bed to increase absorption capacity, followed by a heating phase to release sorbed gas for further use. It is claimed (E. Williame, pers. comm.) that the process leads to about 30% to 70% reduction in new methyl bromide use, depending on the situation of the fumigated enclosure (e.g. freight container) and what load is treated These estimates are consistant with expected residual concentrations from good practice fumigations, such as those indicated in Table 3-1. A model for absorption on a carbon bed at ambient trempterature, followed by higher temperature desorption, is given in Joyce and Bielski (2008).

An example of a commercial installation of a carbon-based recapture system is in operation at Nelson, New Zealand. This port has a substantial trade in export timber that require QPS fumigation with methyl bromide. The installation commenced operation recently (summer 2009) and was required to meet recently modified local air quality standards. The Nelson air quality standards, unique to this port, require capture to 5ppm v/v for containers, and for bulk timber fumigations, reduction until emissions in the ventilation system do not exceed 2.2 g/sec in all flues combined.

The company uses two of the standard sized Nordiko units for shipping containers either on their own or in series. Each filter contains 70 kg of carbon and either single filters or two filters in a series are used, depending on their degree of saturation. The original idea was to build a single large unit to handle the larger export timber fumigations but the two container sized units have been utilised by breaking down the stack sizes to smaller multiple stacks, an arrangement which likely uses more MB.

The typical volume of under-tarp fumigation of export timber was 200 m^3, with a recapture time for timber stacks of 2-4 hours for 48 or 56 g m^{-3}(according to temperature) for the under-tarp QPS fumigations against the wood pest, *Arhopalus tristis*. The total volume of under-tarpaulin fumigation over four months was approximately 15,000 m^3 with an input of around 780 kg of MB. With an expected 5% leakage and high sorption into timber frequently only 40% of the gas input is available for capture. Approximately 3.5 tonnes of absorption carbon were used.

The carbon-based recapture/destruction systems have similar Destruction and Removal Efficiencies (DREs), >95%, to the destruction processes for the only dilute source so far approved by the Parties and added to the list of Approved Destruction Processes (TEAP 2006). These are the municipal waste incineration and rotary kiln incineration processes for dilute CFC sources obtained from foams (Annex II, Report of 15MOP).

The DRE values are based on the assumption that the destruction system used, thiosulphate washing or incineration, is 100% efficient and that there are no inadvertent losses during the destruction process. Measurements in support of this assumption have not been supplied. None of the submissions described any toxic byproducts arising from the destruction processes.

Subject to the constraints on good housekeeping and emissions set out in Annex III and IV of the Report of the 15th MOP, appropriately amended to take into account the special chemical and use features of methyl bromide, Parties may wish to consider adding carbon-based recapture/ destruction systems (thiosulphate washing or incineration) to the list of Approved Destruction Processes. A stipulation that the processes must achieve a DRE of >95% would be consistent with restrictions on Approved Destruction Processes for dilute ODS sources from foams.

Economics of Recapture, Reuse and Destruction Technologies

At this time, recapture technologies generally have not been fitted to methyl bromide fumigations in response to the need to restrict emissions of Ozone-Depleting Substances. This is despite Decisions VII/5 and XI/13, both of which urge, in part, fitting of recapture equipment where technically and economically feasible. Some local regulations restrict quantities of methyl bromide that are released from fumigations. Others provide stringent limits on the maximum concentrations of methyl bromide that can occur in the workspace and environment around a fumigation. These regulations and requirements are related to local air quality and the need to restrict emitted methyl bromide to very low levels. It is these regulations associated with local health and safety considerations that have mainly driven the installation and use of recapture equipment.

Fitting recapture equipment increases the overall cost of carrying out QPS and other methyl bromide fumigations. The actual cost increase per fumigation is highly dependent on situation and throughput. To a first approximation, it appears that fitting and operation of recapture equipment typically doubles the cost of a fumigation with methyl bromide.

In a presentation to MBTOC-QSC (E. Willaume, pers. com.), it was stated that the Desclean recapture/reuse system would cost an extra 34 euro per container fumigation, with a present cost of methyl bromide fumigation without recapture of about 150 euro. This is for treatment of 1000 containers a year over 3 years – a high and sustained rate of treatment.

For an installation on export log fumigations in Nelson, New Zealand, recapture has doubled the cost of fumigation per m^3 of timber. Exact costs in practice have not yet been determined as the problem of disposal of the loaded carbon has not yet been fully solved. As the major fumigations in Nelson are seasonal, the equipment is on long term lease and the equipment cannot be used elsewhere, the costs have to be carried and loaded onto the fumigations. Some exporters have already switched export ports to ones not requiring recapture to avoid the extra costs.

Regeneration or disposal of the carbon that is loaded with recaptured methyl bromide is a significant component of the recapture process. Recovery and reuse of the methyl bromide is an attractive option, avoiding these costs. The sorbed methyl bromide can be released by various forms of heating of the loaded carbon bed to temperatures of 100-180°C, with appropriate temperatures depending on the desorption isotherms for the particular carbons used and degree of recovery needed. The Desclean system (Desclean 2009) can effectively recover recaptured methyl bromide for reuse.

The quantity of methyl bromide that is potentially and in practice available for reuse depends on local design of the fumigation system and the commodity treated. Specifications for efficiency of recapture for certification by Belgian authorities for recapture units require the unit to be able to recapture at least 80% of methyl bromide remaining in the free space from a dosed empty enclosure. In practice, because of sorption and other losses, recapture efficiencies are often substantially less than this (see Table 3-1), limiting the quantity of methyl bromide available for reuse. Thus for new fumigations, it is necessary to top up any dosing from recaptured gas with newly produced methyl bromide.

The cost of newly produced methyl bromide is small compared with the cost of recaptured gas. Thus, in absence of other considerations, the cost savings for using recovered methyl bromide do not, on their own, justify its use compared with recovery and destruction systems.

There is continued debate in some jurisdictions on the registration status of recaptured methyl bromide for reuse.

Recapture Systems Under Development

An Indian manufacturer of methyl bromide, Intech Pharma Pvt Ltd, is currently developing a scrubbing and destruction system for methyl bromide released from fumigations (IPPL 2009). Commercial installations of methyl bromide recapture equipment are typically limited in size to absorption capacities of less than 50 kg methyl bromide. An installation capable of absorbing 484 kg per fumigation is to be installed at Stockton, California, USA, on a fumigation facility processing imported grapes from Chile. The unit is based on a carbon bed absorber with regeneration with a thiosulphate wash (Joyce P. pers. comm., BACT 2009).
In New Zealand, most QPS methyl bromide is used for large capacity fumigation of export logs. Feasibility of a capture system with the appropriate capacity, possibly 500kg methyl bromide, is being investigated.

Studies are in progress in China (Wang Yuejin, QPSTF member) on selection of different types of activated carbon and modification of the characteristics of the activated carbon to reduce the sorption energy of methyl bromide on the carbon for easy recovery. The results show that a much lower temperature of 110°C was needed for complete recovery of methyl bromide from a new type of activated carbon, compared with cocoanut based activated carbon of up to 170°C. Lower recovery temperatures have several advantages, particularly decreased losses from hydrolytic decomposition of sorbed methyl bromide.

Methyl Bromide Emission Reduction in Soil Fumigation

Methyl bromide emissions to the atmosphere from soil fumigation come from any of three major sources (MBTOC 2002; 2007):

- MB emitted through plastic sheets during fumigation;
- MB lost from edges during fumigation; and
- MB emerging from soil after lifting the sheets after fumigation.

It has been estimated that emissions range from is 40-92% from the standard polyethylene (PE) sheeting and from 35-87% for low permeability barrier films (LPBF) (MBTOC, 2002; 2007) Fluxes of MB through LPBF tarps are very low, but loss can occur after lifting the tarp. This is very dependent on the duration of tarping and the soil type and conditions (Yates, 2005; Fraser *et al.*, 2006; Ou *et al, 2007;* MBTOC, 2007). Experimentally, very low emissions can be obtained (e.g. 6%, Yates, 2005). The total MB emitted is unlikely to be 100% of that applied because of breakdown of applied MB in the soil (MBTOC 2002; 2007). Degradation is due to reaction with soil organic matter and some mineral constituents as well as other reaction pathways such as hydrolysis (De Heer *et al.* 1983).

Emission volume release and release rate to the atmosphere during soil fumigation depend on a large number of key factors. Of these, the type of surface covering and condition; period of time that a surface covering is present; soil conditions during fumigation; MB injection depth and rate; and whether the soil is strip or broadacre fumigated are considered to have the greatest effect on emissions.

Barrier Films
Studies under field conditions in a number of regions and countries, together with the large-scale adoption of barrier films in Europe, and more recently the USA, support the use of these films as a means to reduce MB dosage rates and emissions (López-Aranda et al., 2000; Hamil, et al., 2004; Gilreath and Santos, 2005; Hanson et al., 2009). Controlled studies have also shown substantial reductions in MB emissions (Wang, 1997; Yates, 2005; Fraser et al., 2006). The State of California in the US, however, has a regulation which prevents implementation of VIF (California Code of Regulations Title 3 Section 6450(e)). It was implemented because of concerns over possible worker exposure due to altered flux rates of MB when the film is removed or when seedlings are planted.

Barrier films consists of either 1) multi-layer laminates with outer layers of low density polyethylene and a barrier layer of polyamide or ethylene vinyl alcohol, or 2) a mixture of these materials, often called an 'alloy' or 3) two layer, metallised polyethylene films.

Barrier films reduce MB emissions from soil fumigation by keeping the MB in the soil to allow for degradation (Yates *et al.* 1998) when:

- The entire field is covered with VIF film;
- All film strip over-laps are well glued and sealed;
- The VIF film edges are sealed (buried under soil);
- The MB is injected deeply in the soil;
- The film is kept on the field, completely sealed, for 10 to 20 days; and
- The soil temperature, moisture and organic matter content are optimal - medium temperatures, moist soil, and high organic matter.

Barrier films are less effective at reducing MB emissions from soil fumigation (Rice *et al.,* 1996; Thomas, 1998; Wang *et al.,* 1999) when:

- Only part of the field is covered with VIF;
- Any of the film strip over-laps become unglued or are otherwise unsealed;
- Any of the film edges anywhere around the field become unsealed;
- The film seal is broken before 10 to 20 days have passed; and
- Soil temperature, moisture, organic matter are in any way sub-optimal (hot, soil dry or very wet with little organic matter).

Studies have shown that, with traditionally laid plastic films, most unreacted MB either passed through the films or was emitted from the edges of the film (Yates, 2005). In general fumigation films remain in place for 5 to 7 days and with standard films this ensures maximum effectiveness of the applied dose. With barrier films, even though lower doses of MB are used, longer periods of tarping may be required to ensure complete degradation of MB dosage applied and to effectively reduce MB emissions and avoid off gassing.

Increased Chloropicrin Content with Decreased MB

One key strategy to reduce MB dosage and therefore relative emissions has been the adoption of MB:Pic formulations with lower concentrations of MB (e.g. MB:Pic 50:50, 30:70 or less). MB/Pic formulations with lower concentrations of MB (e.g. MB/Pic 50:50, 45:55 or less) are considered to be equally effective in controlling soilborne pathogens as formulations containing higher quantities of MB (e.g. 98:2, 67:33) (e. g. Porter et al., 1997; Melgarejo et al., 2001; López-Aranda et al., 2003; Santos et al., 2007; Hamill et al., 2004; Carey and Godbehere, 2004; Gilreath and Santos, 2005; Hanson et al., 2006; Hanson et al, 2009). Where such formulations are registered or otherwise permitted, they can be used for pre-plant soil fumigation with excellent results. Their use can be achieved with similar application machinery that allows co-injection of MB and Pic or by use of premixed formulations.

Consistent performance has been demonstrated with both barrier and non-barrier films. This includes rates as low as 75 kg/ha (7.5 g/m2) in 250 kg/ha of 30:70 or 33:67 mixtures or 100 kg/ha (10 g/m2) of MB in 250 kg/ha of 50:50 MB/Pic mixtures in conjunction with barrier films as these have shown similar effectiveness to higher rates of MB in 67:33 MB/Pic and 335 to 800 kg/ha (33.5 to 80 g/m2) of MB 98% with standard polyethylene.

Irrespective of what type of surface barrier is used to contain MB during soil fumigation, there are a number of key factors which affect emissions of MB during soil fumigation. Recent reports (Yates, 2005; 2006) have shown that manipulation of many other factors can reduce emissions of applied MB, but the extent to which these factors are practiced by industry is unreported.

Yates concluded that emissions can be reduced by improving containment of the methyl bromide gas and by increasing degradation time, however natural soil degradation is insufficient to reduce fumigant emissions to the atmosphere. Methods to improve containment included barrier films as discussed above, but also improvements in cultural factors of the cropping system including soil management, e.g. strip verses broadacre treatment, increased containment time, addition of sulphur containing fertilizers, increasing organic matter, soil water content, soil compaction and surface sealing with water (MBTOC, 2007).

Phytosanitary Standards of IPPC and Recommendations on Use of MB

IPPC Phytosanitary standards have approved the use of methyl bromide for specific phytosanitary treatments, provided that practical measures are taken to control or reduce its emission during use. The non-availability of commercially available cost-effective alternatives to methyl bromide does also influence IPPC standards to continue to approve use of methyl bromide where necessary. The recent IPPC Recommendation on the ‘Replacement or Reduction of the Use of Methyl Bromide as a Phytosanitary Measure’ has encouraged parties to put in place a strategy that will help them to reduce the use of MB and/or reduce emissions (IPPC, 2008, p.4-5). In addition, the latest ISPM 15 standard encourages NPPOs to promote the use of the alternative (heat) treatments approved in the standard (IPPC, 2009b).

Section IV. Conclusion

During its review of regulations, the MBTOC encountered very few regulations which mandated or specified MB use only. However, there are many regulations that require plants to be free of insects and other pests, with MB as the fumigant of choice. Often, the data have not been generated to prove effective control of all pests with an alternative to a standard similar to MB, and Parties are unwilling to adopt the alternative in the face of possible increased risk.
Additionally, the required standard of efficacy for quarantine uses is extremely high because the consequences of exotic pests surviving treatments can be catastrophic to regions where the new pest becomes established. As compared to normal pest control and pre-shipment treatments, quarantine treatments seek to wholly prevent entry of any pest individuals into a country and as such must be as close to 100% effective as possible. A common quarantine standard is probit 9, which states that 99.9968% of pests in the shipment must be killed or made reproductively sterile by the treatment—an extremely difficult target to reach.

In summary, the main barrier to moving completely into methyl bromide alternatives is lack of data about alternatives. The U.S. EPA encourages applicators – commodity owners, shippers, and their agents to review potential alternatives outlined in this document as well as any others that may be missing, and also to submit additional efficacy data, to promote the complete transition away from methyl bromide for all uses.

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